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# Composite Load Spectra for Select Space Propulsion Structural Components

## Final Report

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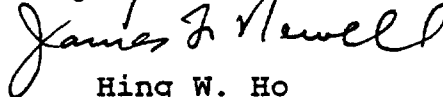
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## 1.0 INTRODUCTION

The objective of the Composite Load Spectra (CLS) program is to develop generic load models, with multiple levels of progressive sophistication to simulate the composite (combined) load spectra that are induced in space propulsion system components, representative of Space Shuttle Main Engines (SSME), such as transfer ducts, turbine blades and liquid oxygen (LOX) posts. These models will be developed using the coupled model approach.

The CLS coupled model approach, consists of developing coupled models for composite load spectra simulation which combine the (deterministic) models for composite load dynamic, acoustic, high-pressure and high rotational speed, etc., load simulation using statistically varying coefficients. These coefficients will then be determined using advanced probabilistic simulation methods with and without strategically selected experimental data.

The unified theory required to combine the various individual load simulation models (hot-gas dynamic, vibrations, instantaneous-position, centrifugal field, etc.) into composite load spectra simulation models will be developed under this program. A computer code incorporating the various individual and composite load spectra models will be developed to construct the specific load model desired. Applications of the computer code to various components in conjunction with the PSAM (Probabilistic Structural Analysis Method) project whenever possible to perform probabilistic load evaluation and life prediction evaluations.

## 2.0 SUMMARY

This is a follow-on effort of a previous NASA Lewis Research Center (LeRC) contract, "COMPOSITE LOAD SPECTRA FOR SELECT SPACE PROPULSION STRUCTURAL COMPONENT" (CLS). In the previous (CLS) effort (Ref's 2.1-2.5), the following major tasks were accomplished:

(1) The probabilistic methods: (i) the Gaussian algebra method, (ii) the RASCAL method, a variance of the discrete probability distribution (DPD) method, and (iii) the Monte Carlo method, were developed and implemented for engine component load simulation.

(2) The probabilistic load modeling methodology for load simulation was developed. The engine system influence model simulating the operation and performance of a space shuttle main engine (SSME) was chosen as a base engine model, and the coupled component load models for various loads of the four selected components: (i) the HPFTP turbine blade; (ii) the HGM transfer ducts; (iii) the LOX post and (iv) the HPOTP discharge duct were developed and verified with available SSME flight/test data and deterministic analysis models.

(3) Expert system techniques were implemented to manage the engine load information and data and interface with users for consultations and/or preparation of load simulation tasks. Expert system user interface system (or query system) and intelligent database system software were designed, implemented and tested. Load databases were created to store modeling information and load data. Rule modules in decision tree format were implemented to perform various data retrieval and load model consultation tasks.

For the current effort, the tasks include (1) the integration, validation/verification and documentation of the CLS computer software developed in the previous CLS contract; (2) continue to develop advanced physical coupled models and applications to further enhance the CLS component load simulation models; and (3) develop a simple tutorial system to provide helpful information.

### 2.1 CLS Code Integration, Validation/Verification and Documentation

The architecture of the CLS software system was restructured. The significant changes are (1) the separation of the probabilistic method module and the engine load models simulation module and (2) using the object-oriented programming concept to model the engine loads. In the new architecture, generic probabilistic method routines that do not need to know the detail of the load models are implemented. The load databases are also isolated from the probabilistic method routines. The load simulation module is a deterministic multi-level coupled engine model that can be easily removed from the code and be replaced by another load simulation module. Code debugging and reliability are greatly improved. The separate

probabilistic method routines are independently verified and will not be affected by the implementation of new component load models.

Using the object-oriented concept, each component load is treated as a different object. It has its own load evaluation method. Of course, a generic load model such as a simple linear scaling model is also treated as an object. Loads that use the model can send in the required information and activate the model. This type of programming concept helps simplify the implementation of a complex load model.

The CLS computer codes are fully debugged and tested. Quite a few enhancements such as the multiple-nodal-value storage management scheme, the equivalent time scheme for transient load simulation and enhancement on the thermal load options, etc., were incorporated into the CLS codes. The CLS computer program LDEXPT user's manual (APPENDIX B) serves as a documentation of the load models and the CLS codes.

## 2.2 Advanced Physical Modeling

Three advanced modeling tasks were carried out: (1) the 5000+ nodes finite element model (FEM) HPFTP turbine blade thermal load for duty-cycle-data mission profile (engine start transient, steady state, and engine shutdown transient), (2) the probabilistic fluctuating pressure load simulation of the HPOTP discharge duct, and (3) the CLS vibration scaling model.

The turbine blade thermal load simulation previously demonstrated was only for steady state operating conditions. This analysis was extended to a duty cycle representation to demonstrate the thermal shock uncertainty modeling. The 5000+ node model temperature profiles for a typical duty-cycle-data (DCD) mission was generated. Nodal temperature reference profiles of 62 time slices for the first 20 seconds of engine operation from engine start and temperatures of 50 time slices for the last 5 seconds of engine shutdown transient were included. Effect of the start transient spike of the HPFTP turbine inlet temperature was modeled. A thermal influence model was developed for the 5000+ nodes FEM turbine blade for coupling with the engine system model to perform probabilistic thermal load simulation of a HPFTP turbine blade. With the thermal influence model and the DCD reference temperature profile file, a turbine blade DCD thermal load model was implemented to the CLS engine load module.

Application of the CLS advanced fluctuating pressure model for ducts to high pressure oxidizer turbopump (HPOTP) discharge duct was demonstrated. Coupling of the stand-alone probabilistic fluctuating pressure analysis code FLAPR/BENDS to the CLS engine system model was achieved. The HPOTP pump noise and the duct bend noise due to flow separation were modeled as a noise input power density spectra. The analysis produces the fluctuating pressure

gain frequency response functions at different nodes along the HPOTP discharge duct.

The vibration load modeling task finally produces good results with a CLS component scaling criteria (CLS-CSC) model. The CLS-CSC model differs from the Barrett scaling in that it uses the component specific power to scale the vibration load instead of the total engine specific power. The CLS-CSC model brings in a geometry lumped parameter ( $K_f$ ) to account for the geometry effect of the flow passage for the turbopumps. The CLS-CSC vibration load model reduces the 4 SSME pumps into a single scaling straight line.

Application of the CLS load simulation technology to two component structural life prediction/evaluation tasks will be described in a later section. They demonstrate the integration of the CLS tools with other probabilistic analysis codes and the benefit of the availability of the CLS tools.

### 2.3 CLS Hypertext Tutorial System

A simple hypertext system was implemented for the CLS expert system. The hypertext system retrieves "cards" of text with "buttons" which are key-words provided by the system. The system has a few simple commands to list available buttons and to scroll text. The task has demonstrated the feasibility of the system.

## 2.4 References

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### 3.0 CODE INTEGRATION AND VALIDATION/VERIFICATION

#### 3.1 ANLOAD CODE VALIDATION/VERIFICATION

The function of the load simulation module ANLOAD is to synthesize rocket engine system dependent load and component load probabilistic distributions. Fig. 3.1 depicts the structure of the ANLOAD module. The probabilistic method module (tool box) and the CLS engine load model module are two independent modules of ANLOAD. Three probabilistic methods have been implemented (Ref. 2.4): (1) the Gaussian method, (2) the RASCAL method and (3) the Monte Carlo method. The manager routines assign time step size and duty cycle mission phase related parameters to run the load simulations. All load databases required for the simulation are obtained from an input file. The input file could be prepared manually or automatically by the CLS load expert system. This loosely coupled configuration imposes a minimum constraint to the interface requirement of both the load simulation module and the load expert system module. The requirement is that the expert system knows what the load simulation module needs and supplies all the required databases to it in the input file.

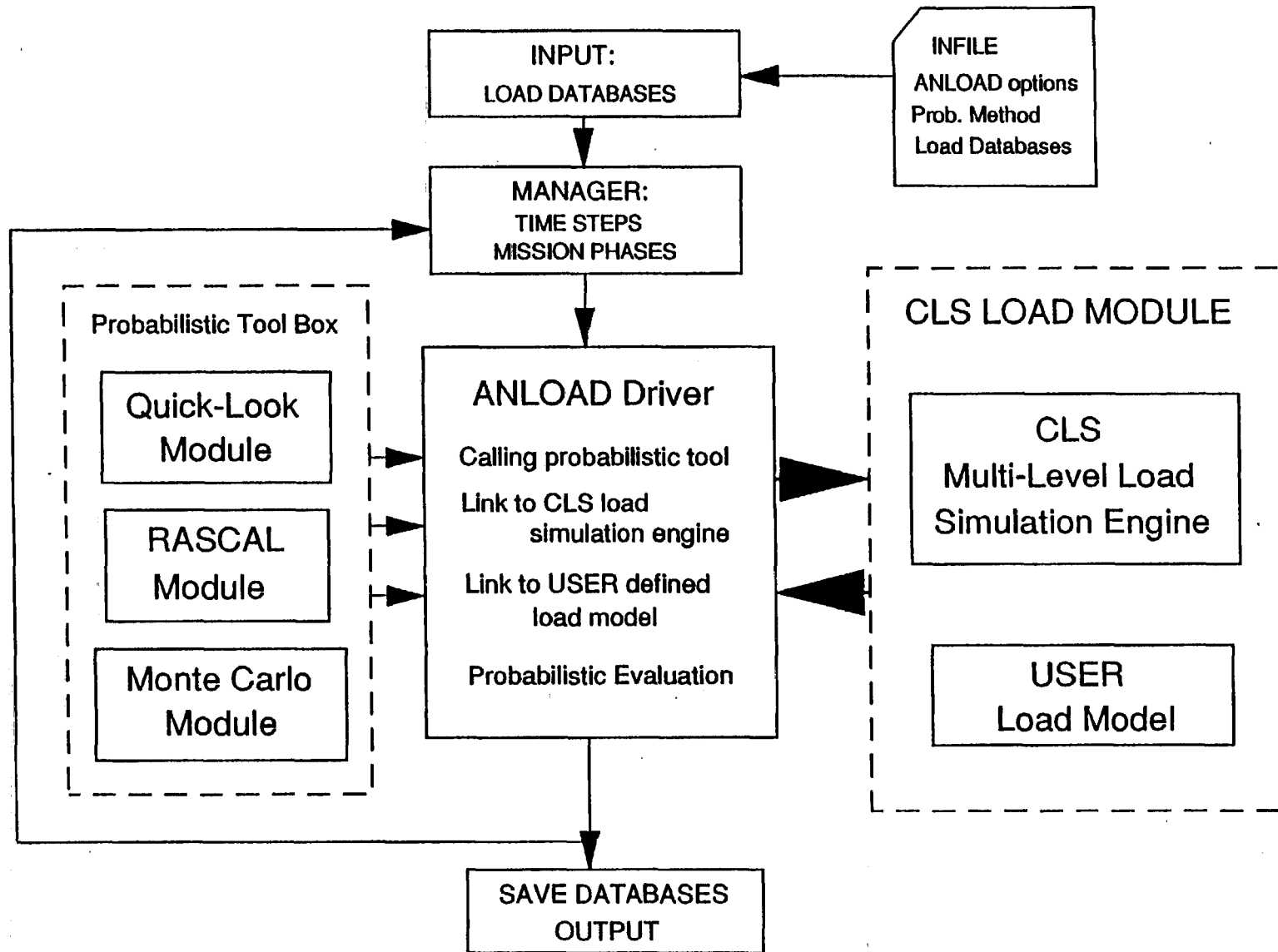
#### Generic Probabilistic Method Module

The goal is to have a reliable ANLOAD module that is easy to maintain. The reliability can be achieved by (1) clearly defining and documenting the variables, (2) removing all coding that is no longer used, and (3) making the probabilistic method routines as generic as possible to facilitate the implementation of additional component load simulation.

Making the probabilistic method module RASCAL generic increases the reliability of the module. A generic RASCAL module means that adding a new engine model, a new load function or modifying an existing engine model will not change the coding of the RASCAL method. The RASCAL method is a probabilistic method which combines independent random variables according to a given function (combined function) to obtain the value of a dependent variable. The procedure is generic if it does not depend on the combined function. The generic RASCAL module does not change no matter which of the variable combined functions (load models) is called. The generic code requires a set of generic interface routines for communications with the combined functions.

The procedure of the RASCAL method includes defining discrete probability distributions (DPD) of input random variables, sampling the input variable DPD's and combining them according to a combined function, condensing the values of the combined function into a DPD of the dependent variable. To make RASCAL module generic, the two load model dependent processes: defining input random variable distributions and the combining routine where the combined function

Figure 3.1 CLS ANLOAD Load Simulation Module



is defined, are isolated from the RASCAL method module. The input distributions are now passed to the RASCAL routine as arguments. These same distributions are then passed to the combining routine where model dependent information and data are available to carry out the combine task. Fig. 3.2 illustrates this generic design. Notice how cleanly the interfaces between different processes are defined. The RASCAL routine does not need to know any thing about the engine models as defined in the combined functions and how the DPD's are stored in the ANLOAD program.

### New ANLOAD Architecture

The new architecture has two essentially independent modules that are loosely coupled together. The two modules are the generic probabilistic method module and the engine load module. The probabilistic method module is implemented as a tool independent of the engine load models. The advantages of this architecture are (1) it allows parallel implementation of different probabilistic methods such as the RASCAL and Monte Carlo methods without changing the codes of the engine load module; (2) it allows a natural implementation of a multi-level engine coupled model independent of the probabilistic methods used in the code; and (3) it allows parallel implementation of engine load models without changing the codes of the probabilistic tools. With this architecture, implementation of additional load modules for an engine component will be clear-cut, straight forward, and more reliable.

### CLS Tightly Coupled Engine Load Module

The engine model implemented in CLS is a multi-level engine model that couples each individual component load model to an engine system model (Fig. 3.3). The loads of the engine model can be classified into four major categories: (1) the component loads that are internal to the component (e.g. the pressures and temperatures of the LOX post); (2) the component local 'loads' or variables (e.g. the LOX post hot gas heat transfer film coefficient); (3) engine system dependent 'loads' which include the engine performance variables and the sub-system interface loads (e.g. the MCC hot gas injector pressure and the HPFTP turbine discharge temperature); and (4) the engine system independent 'loads' or variables, also called primitive variables which include engine inlet operating condition loads (e.g. the engine inlet fuel pressure) and engine hardware variables (e.g. HPFTP turbine efficiency multiplier).

The current architecture for ANLOAD makes the probabilistic method module generic and separates the probabilistic method tools and the engine load models. The probabilistic method module need only send a set of input values to the engine module and ask to receive a set of output values from the engine module. The probabilistic method module does not need to know anything about the engine model module.

Figure 3.2 GENERIC RASCAL MODULE

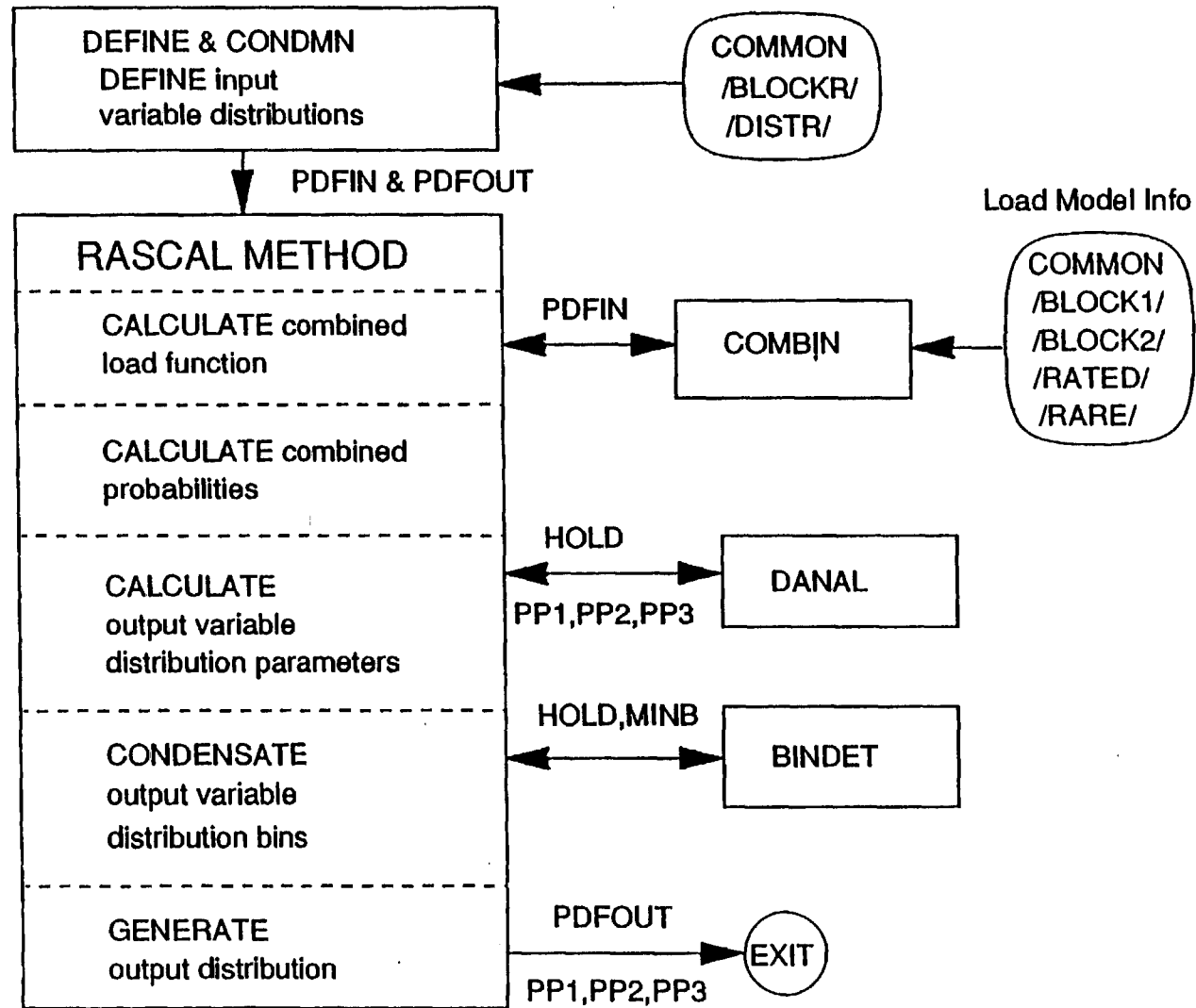
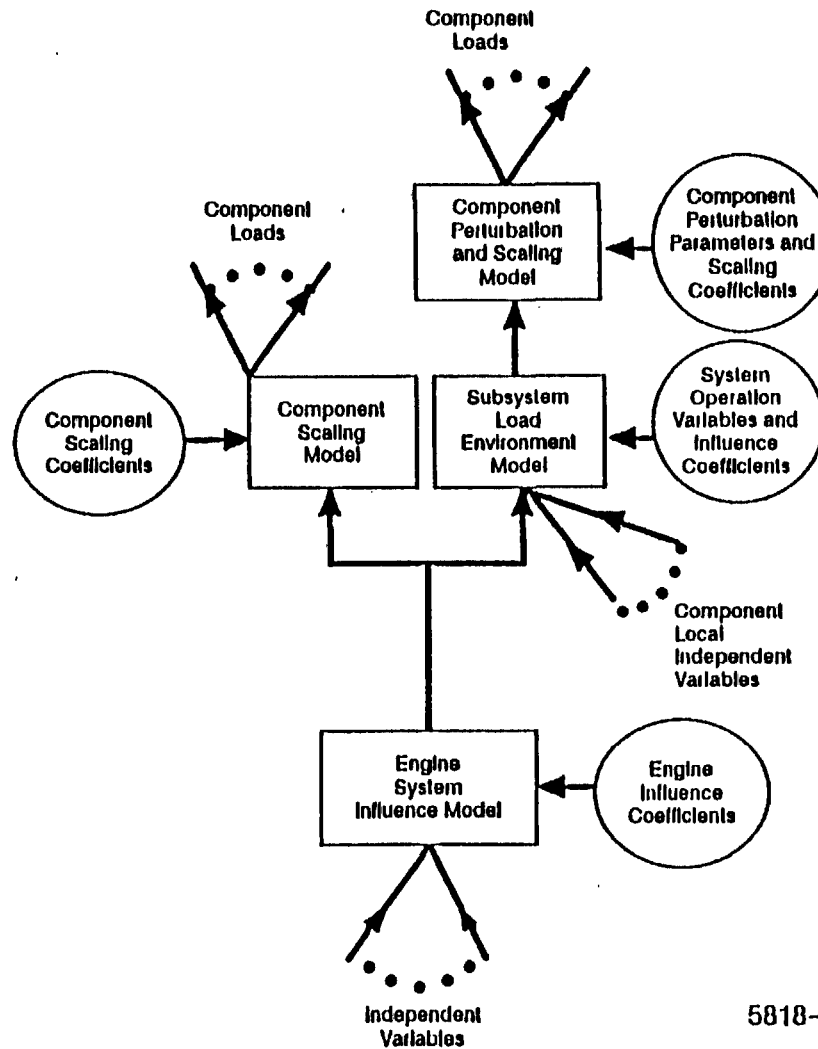


Figure 3.3 CLS Multi-Level Coupled Engine Model



The CLS engine models developed for the ANLOAD probabilistic load simulation module are deterministic engine models. They can be used in a deterministic load analysis as well as a probabilistic load analysis. An engine model developer can now develop additional component load models or a new engine model independent of the probabilistic methodology. The engine model developer furnishes the load model information to the CLS load expert system (LDEXPT) analyst to implement new load model to the CLS code. The LDEXPT analyst needs to setup a new database for the load model, implement the query interface, build a rule-base module to retrieve the load model information, and add a new option to ANLDIN module for preparing ANLOAD input file for the new loads.

The new architecture as shown in Fig. 3.1 fits very well with the DPD/RASCAL method and the Monte Carlo method. ANLOAD driver can call in easily the RASCAL module or the Monte Carlo module to carry out the load simulation. It could be just as easy to call in modules of advanced Monte Carlo methods, if implemented, such as the Latin Hypercube method. Linking to the CLS load module is just as easy. In fact, the CLS engine model can be unplugged and replaced by any other engine models that users may have.

The CLS multi-level load simulation engine is a deterministic engine model for the Space Shuttle Main Engine (SSME). It was used as the deterministic engine model as the one embedded in the probabilistic structural analysis used for a LOX post threaded region LCF and HCF deterministic analysis and reused as part of the LOX post probabilistic analysis. The embedded CLS multi-level engine model is a reduced set of the complete model. A user defined engine load model can also be easily implemented by coding the engine model into a subroutine UZFUN.

This new ANLOAD code makes the validation and verification of the code easier. Each model needs only be verified once and so do the probabilistic tools. Implementation of new component loads becomes so much easier and more reliable. Thus the reliability and productivity of the code are maintained.

### Multiple-Nodal-Values Storage Management Scheme

As mentioned earlier it is not easy to implement a completely generic probabilistic method module. Loads that have multiple nodes such as turbine blade pressures and temperatures on a turbine blade finite element model (FEM) cause a break down in the generic nature of the probabilistic method modules. The probabilistic method modules are required to know that the load variables have multiple node values. That means the probabilistic method modules need to know something about the load variables that are evaluated. The other problem presented by the multiple node load variables is the storage management problem of saving all the intermediate results. A few thousand nodes finite element model will require a few thousand double precision words of storage per simulation. A ten thousand Monte Carlo simulation will then require several tens of million of double precision words for storing the intermediate results for a load simulation run.

For the storage scheme, it is specified in general that the maximum sample size for each time step for an output variable will not exceed one million. If there are more than one output variable, then the output variables have to share the storage among them. With this specification, an array OUTDRV(1000000) of a million double words is used as a storage area. A scheme of storing the intermediate load values is designed and implemented. For each FEM multiple-nodes component load, the number of output variables is the number of nodes of the FEM. The product of the number of output variables and the sample size cannot exceed one million if a fast load simulation is desired.

In CLS implementation, the results of the intermediate load calculations (i.e. the load calculation of each sampling step) are saved to a file named 'SCLMSAV'. This file is very useful for post-processing to obtain more detailed statistical results such as correlation between two system dependent loads or the sensitivity factors of an output load to a primitive variable. As a by-product, with the intermediate load values saved at each sampling step, one can increase the number of output nodal values to a million and has no limit on the number of sample size for a simulation. However, this means that the code has to read the SCLMSAV file to obtain the nodal values of the output component load for generating the information of the output distribution function. The reading of the SCLMSAV file would significantly slow down the simulation.

### CLS Engine Coupled Model Validation/Verification

With the ANLOAD coding for the new architecture and generic probabilistic method modules of RASCAL and the Monte Carlo method in place, the CLS engine load module was implemented and tested. The CLS engine load module was also improved. The component load models were treated as load objects. Depending on the load types,

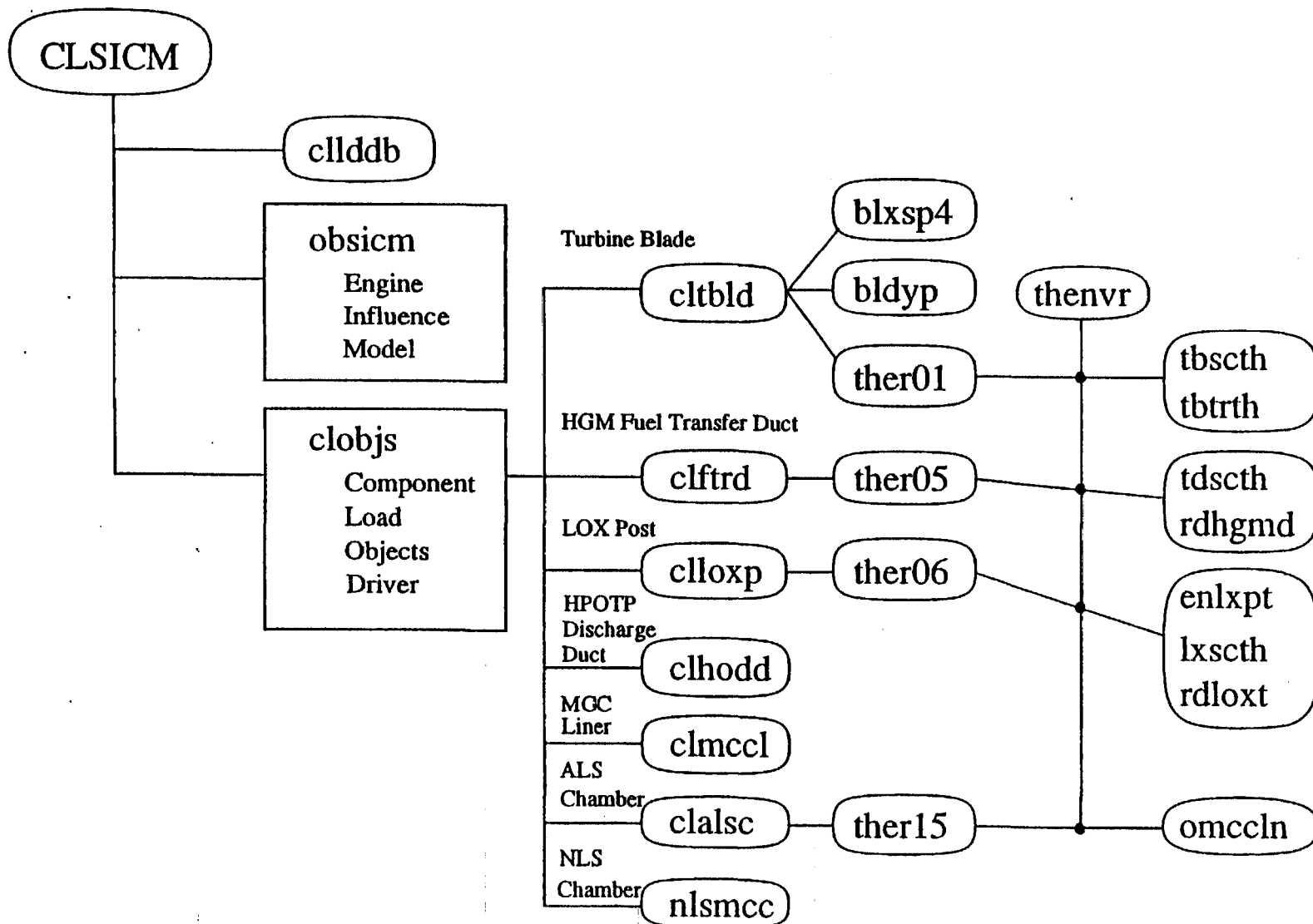
some loads are evaluated with generic load models such as linear scaling model and linear thermal influence model, some loads are evaluated by calling their own load object functions, which are typically for modeling more complex load model. Fig. 3.4 the code structure of the engine load module. All load models were tested.

The SCLM (Structural Component Life Model) was the first load model to link with the generic RASCAL module to validate the newly implemented code structure. The sample case was a SCLM main combustion chamber (MCC) coolant channel load model, previously developed for a MCC liner life prediction analysis. With minimal effort, the test case ran successfully. During the test runs, the intermediate results from SCLM were also printed to the output. The load calculation was verified with manual calculations. The test case clearly demonstrates the ease of adding a new component load model to the load simulation system and the reliability of the system.

The SCLM LOX post component load model for the LCF and HCF failure modes and the SCLM high pressure oxidizer turbopump discharge duct load model were also easily implemented. The component load models implemented to the engine model are tightly coupled to the engine system influence model. Since they are directly coupled, all correlations between engine system variables and component loads are preserved.

The multiple-nodal-values storage management scheme is tested with the FEM HGM fuel transfer duct thermal load model. The FEM has 237 nodes and is well within the size limit of the storage scheme. The test was successful. The 5000+ nodes FEM turbine blade thermal load model also utilizes the storage management scheme. The detail of the load model is described in the component load model section of the CLS load simulation expert system LDEXPT user's manual. Suffice to say, the 5000+ nodes FEM turbine blade thermal load module was successfully implemented to the load simulation module ANLOAD.

Figure 3.4 CLS Load Module CLSICM



### 3.2 CLS Expert System Enhancement and Validation/Verification

The CLS expert system module LDRBMS includes the rule base management system RBMS and knowledge base management system KBMS. All rule modules in RBMS were tested and documented. Two major enhancements make for version 5.0 of the code are the knowledge base input/output (KBIO) upgrade to an indexing scheme and the addition of a tutorial system. Both enhancements increase the efficiency and user friendliness of the code.

#### 3.2.1 CLS KBIO Module Enhancement

The CLS knowledge base file Input/Output module KBIO was upgraded to improve the efficiency of database (or knowledge base) retrieval and storage. This enhancement should reduce the databases retrieval time dramatically.

An indexing scheme was implemented to the file I/O routines. The scheme is based on an index sequential access method (ISAM). An index table is built when a file is first created. The index table of the file will be updated every time a new block of data is added to the file. The index table is permanently saved in the last block (namely, the end-file group block) of the file.

#### Summary

The result of the enhancement task of the knowledge base Input/Output (KBIO) module is satisfactory. To benchmark the result of the enhancement, the SCLM (Structural Component Load Model) rule module was selected to run with both the old and the new KBIO systems. The SCLM task is to generate a list of component loads and system loads and evaluate their values using the engine system influence model. The total number of "loads" including the engine primitive variables is 38.

The total CPU time for the SUN workstation run using the indexing scheme is 1 minute 5.4 seconds. As compared to the non-indexing access method, the efficiency of the KBIO system improves by a factor of 4. The improvement in 'sys time', which is the system overhead time mostly related to system Input/Output (I/O), is significant. Reduction in the I/O time is the goal of this enhancement task and it is achieved with a reduction in I/O system overhead time by a factor of 12. Moreover, with the improved I/O module the user-friendliness of the CLS code is improved. Users see the computer code in action all the time and will not become impatient and begin to wonder if the program is running.

#### CLS KBIO Indexing Scheme

The original Input/Output module was developed in-house for use by the structural analysis codes and thermal analysis codes. The pur-

pose was to have data files having a universal format, which can be easily ported to different analysis codes. The I/O file format was unformatted sequential. The universal file is composed of a file header record, blocks of data groups, a file trailer record and an end-of-file group block. Each data group is composed of a group header record, block of data composed of logical data records, and an end-of-group record (see Appendix B "LDEXPT user's guide"). The I/O module includes a set of routines capable of reading and creating a universal file.

During the early part of the CLS development effort, the I/O module was implemented in the CLS code to take care of the I/O need of the knowledge base file. However, such system does not allow an update of the knowledge base file. The file format was therefore changed to unformatted direct to allow update of the knowledge base file. The read and write operations were not upgraded and remain sequential. As the knowledge base is expanded to include more models and data, the inefficiency of the I/O module becomes obvious.

This enhancement task has completely changed the I/O operation from a non-indexing access method to an indexing access method. The new read and write routines fully utilize the indexing scheme of the direct access method. An index table is saved in the end-of-file group block. It consists of the addresses of the following records: the file trailer record, and the first group header records of each non-contiguous group block of each group and as many as possible the group header records of group blocks within a contiguous group. The total number of addresses or indices of the group header records saved is no more than 17 (limited by the size of the index table). For a data group that has less than 17 group blocks, all addresses of group header records of the group are saved in the index table. Each time a knowledge base file is opened, the end-of-file group is read first to retrieve the group names and the index table. If a new group of data is added to the knowledge base file, a revised end-of-file group will be saved at the end of the file. The new KBIO module is thoroughly tested and run successfully.

### 3.2.2 CLS Hypertext Tutorial System

The CLS tutorial system was implemented to provide on-line tutorials to the user community on the CLS load simulation system. The goal of this task is to implement a working version of the tutorial system and not worry about having sufficient tutorial materials at this time. The tutorial system was implemented using a simple version of the hypertext technology, no advanced artificial intelligence techniques such as building a "student" model (trying to guess a user's intention and difficulties) are explored.

Information and text knowledge are stored in card format. The cards are retrieved with key words. Physically, the text materials are stored in a text file which can be edited and updated with a text editor. This makes building the "cards" a simple task. However, this means that the text file is a sequential file which could slow down the "card" retrieval operation. If it turns out that the system is too slow, the compiled knowledge technique can be used to translate the knowledge into binary direct file to speedup the operation. The CLS's KBIO module with its indexing I/O scheme can be employed for this purpose.

The organization of the tutorial information is an important issue. An ideal organization will require minimal storage and avoid information redundancy. Semantic nets consisting of nodes and links have been developed by early AI (Artificial Intelligence) researchers as a knowledge representation tool. Knowledge represented by nodes can be associated or inferred through the links. In the CLS hypertext tutorial system, the semantic network scheme is used to provide a knowledge representation (Fig. 3.5) and a framework to organize the CLS information into a hierarchical network of semantic nets. It should facilitate the construction of the tutorial files. However, the semantic net representation is only used here to help organize the CLS tutorial materials.

#### Implementation of the hypertext system

The system consists of a "card" information management system, a key-board command lexical analyzer, a command processor and a tutorial text file. The card information management system carries out the information retrieval based on the requested button and display of the card information to the screen. The lexical analyzer analyzes a user input and send it to the command processor and the command processor carries out the command requested. The lexical analyzer and command processor could be expanded and implemented for the expert system driver so that the system can go from a module to another module without going through all those panels of menu that are shown on the screen as it is being done on the present system.

Figure 3.5 CLS HYPERTEXT Knowledge Representation

- USING HYPERTEXT TECHNOLOGY

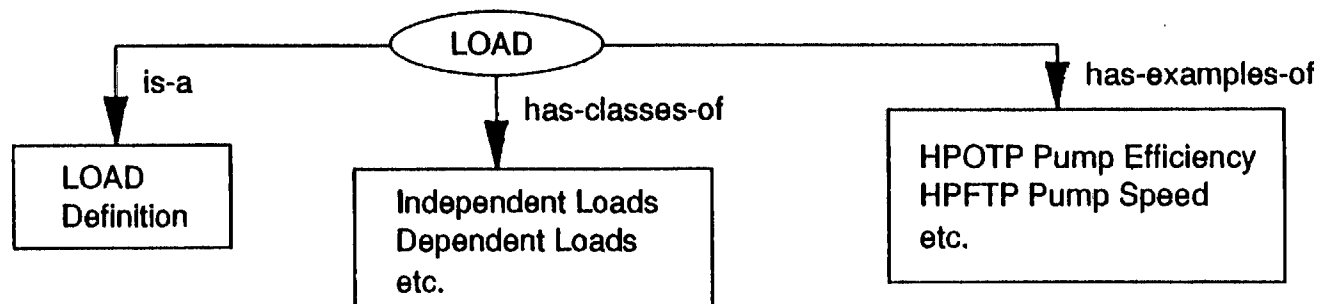
STORING INFO IN INDEX CARD FORMAT

RETRIEVAL OF TEXT WITH KEY WORDS

- USING SEMANTIC NET

TO ORGANIZE INFORMATION

EXAMPLE :



The tutorial text file is deigned to contain "cards". Each card has a button (key-word) serves as an index for information retrieval and a number of lines of text. The number of lines can be more than a screenful. The hypertext displaying routine will display the card information one screen at a time and wait for user command to continue. At the end of the card, a list of daughter-buttons are displayed. One of them can be selected by typing in the button to continue the chain of information. Other buttons can also be selected to branch off to a different chain of information. Fig. 3.6 shows the card as shown on screen when the button "CLS" is entered. Fig. 3.6a shows the button input. Fig. 3.6b is the "CLS" card. At the bottom of the card, a daughter-button "CLS-ENGN" is listed. In this case there is only one daughter-button. For other cards, there could be more daughter-buttons.

The hypertext system has two command sets. The first command set is for moving the card information up and down a number of lines, and moving to the top or bottom of the card file. The second command set is to list the available buttons. It can list the present daughter-buttons, the previously shown buttons or all buttons seen thus far. The following is a list of the hypertext commands.

<u>Command</u>	<u>Function</u>
?LBTN	List the present daughter-buttons
?LBTN P	List previously shown buttons
?LBTN -1	Same as above
?LBTN P 2	List previously shown buttons two levels up
?LBTN -2	Same as above
?LBTN P n	List buttons n levels up
?LBTN -n	Same as above
?LBTN ALL	List all buttons seen thus far
?UP n	Move card info up n lines
?DOWN n	Move card info down n lines
?TOP	Move to the beginning of the card
?END	Move to the end of the card
	These four commands can be abbreviated using only the first letter, e.g. ?U, ?D, ?T, and ?E.

```

***** HTX COMMAND PROCESSOR *****
Please enter Hypertext Button or Command:---?---
CLS

```

(a) htx Input Panel

```

*****
CLS
CLS stands for Composite Load Spectra.
The CLS computer program is a probabilistic load
simulation system that can synthesize component
loads of a space propulsion system :CLS-ENGN:
(rocket engines).

The CLS code has a knowledge base that includes
a large volume of engine load information and data.
It is built as an expert system so that it can
interface with users to perform consultation tasks.

::CLS-ENGN::
*****

```

(b) htx Card: "CLS" Card Information

Figure 3.6 CLS Hypertext System Card Information

## 4.0 ADVANCED PHYSICAL MODELING

Three advanced physical modeling projects were carried out during this contract period: (1) The 5000+ nodes FEM turbine blade thermal load model, (2) the probabilistic fluctuating pressure analysis of the SSME HPOTP discharge duct, and (3) the vibration load scaling model. Detail of the 5000+ nodes FEM turbine blade thermal load model is documented in the CLS load simulation expert system LDEXPT user's manual (APPENDIX B) and References 4.1 and 4.2. It will not be repeated in this section. The probabilistic fluctuating pressure analysis of the SSME HPOTP discharge duct is reported in detail in Ref. 4.3. Some of the high light are presented in this section. The latest results of the CLS vibration load scaling model are presented here. The CLS component scaling criteria for the component vibration loads are discussed in Ref.4.4.

### 4.1 The Probabilistic Fluctuating Pressure load Analysis of SSME HPOTP Discharge Duct

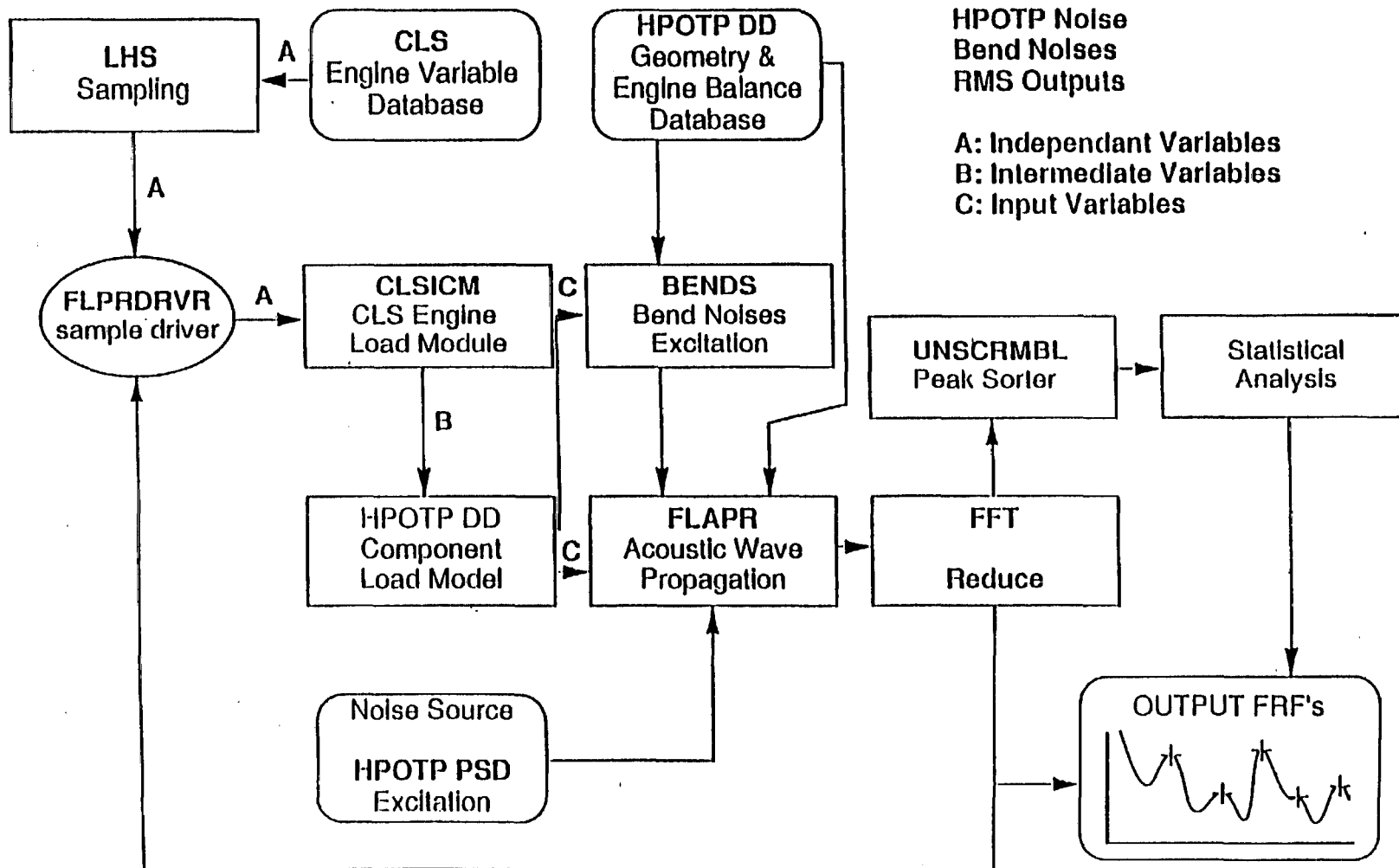
The fluctuating pressure load was evaluated by the stand-alone acoustic load module consisting of the FLAPR and BENDS programs (see references therein in Ref. 4.3). FLAPR is a one dimensional acoustic load propagation code and BENDS is a duct elbow or bend noise generation code. The acoustic load module was coupled to the CLS (Composite Load Spectra) engine load module to provide the link between the acoustic load variables and the engine system independent variables. A subset of the CLS engine load module needed for this analysis is embedded in the acoustic load module. The engine load database required for the analysis was generated by the CLS expert system. The database includes a list of relevant engine independent variables and engine system load variables and a set of engine influence coefficients required for the calculation. The probabilistic analysis was performed using the Latin Hypercube Monte Carlo method. A Latin Hypercube Sampler program (LHS) from Ref. 4.5 was used to generate the random samples of independent variable values.

Fig. 4.1 illustrates the complete process of the probabilistic analysis. A driver program FLAPRDRVR runs the load modules for each LHS sample, performs fast fourier transform (FFT) on the FLAPR time domain acoustic loads and save them for statistical analysis.

There are two sources of noise excitation for the HPOTP discharge duct. Fig. 4.2 is a drawing of the HPOTP discharge duct. One source of noise is the HPOTP pump noise excitation and the other is the duct elbow or bend noise excitation as a result of the flow separation in the duct bend region. Fig. 4.3 shows the excitation spectrum applied to the duct at the pump end as the forcing function. The sinusoidal peaks at 500 hz, 1000 hz, 2000 hz and 4000 hz of the pump excitation spectrum correspond to the pump synchronous, 1x,

# HPOTP Discharge Duct

## PROBABILISTIC ACOUSTIC LOAD ANALYSIS



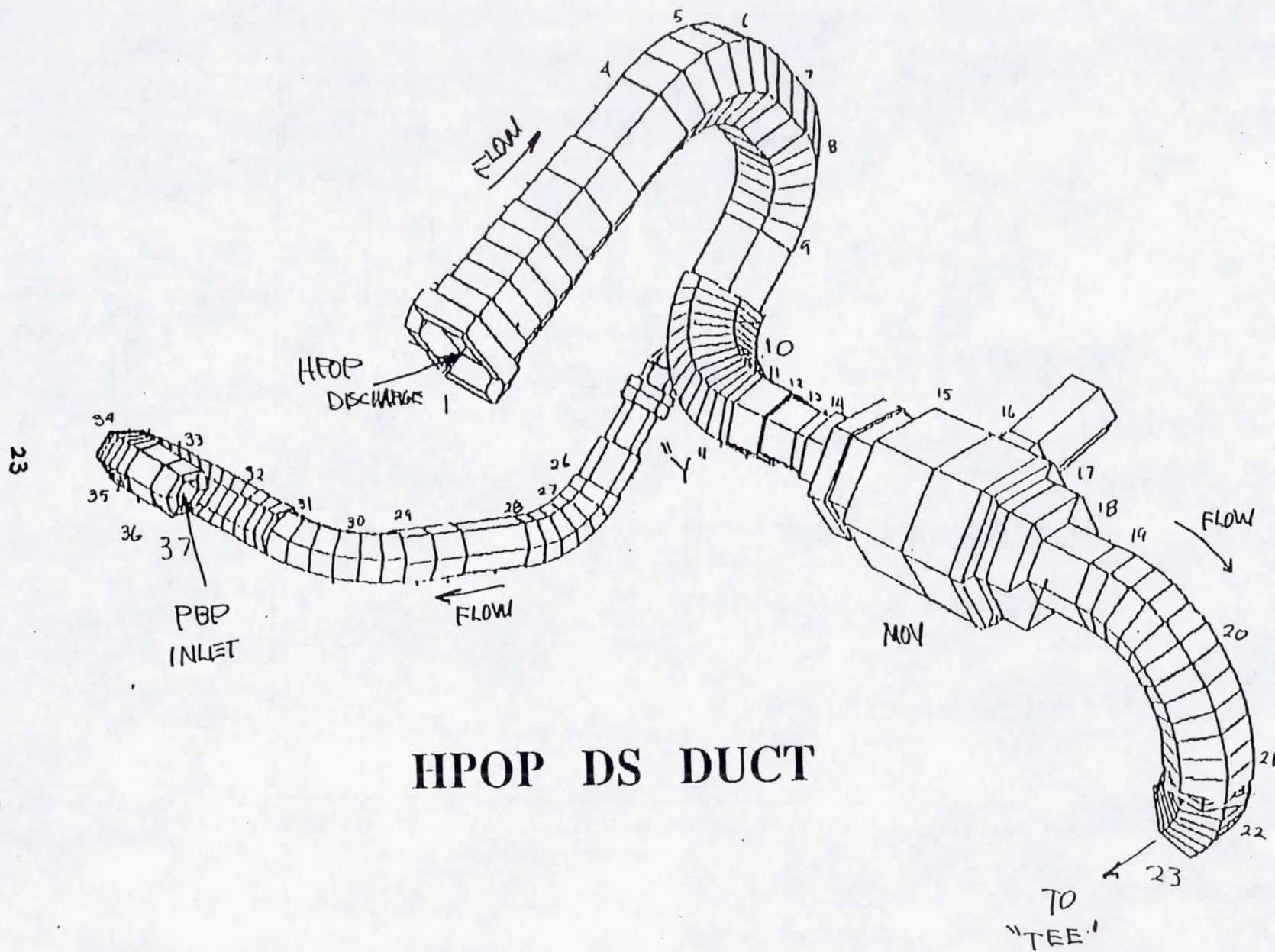


Figure 4.2 HPOTP Discharge Duct

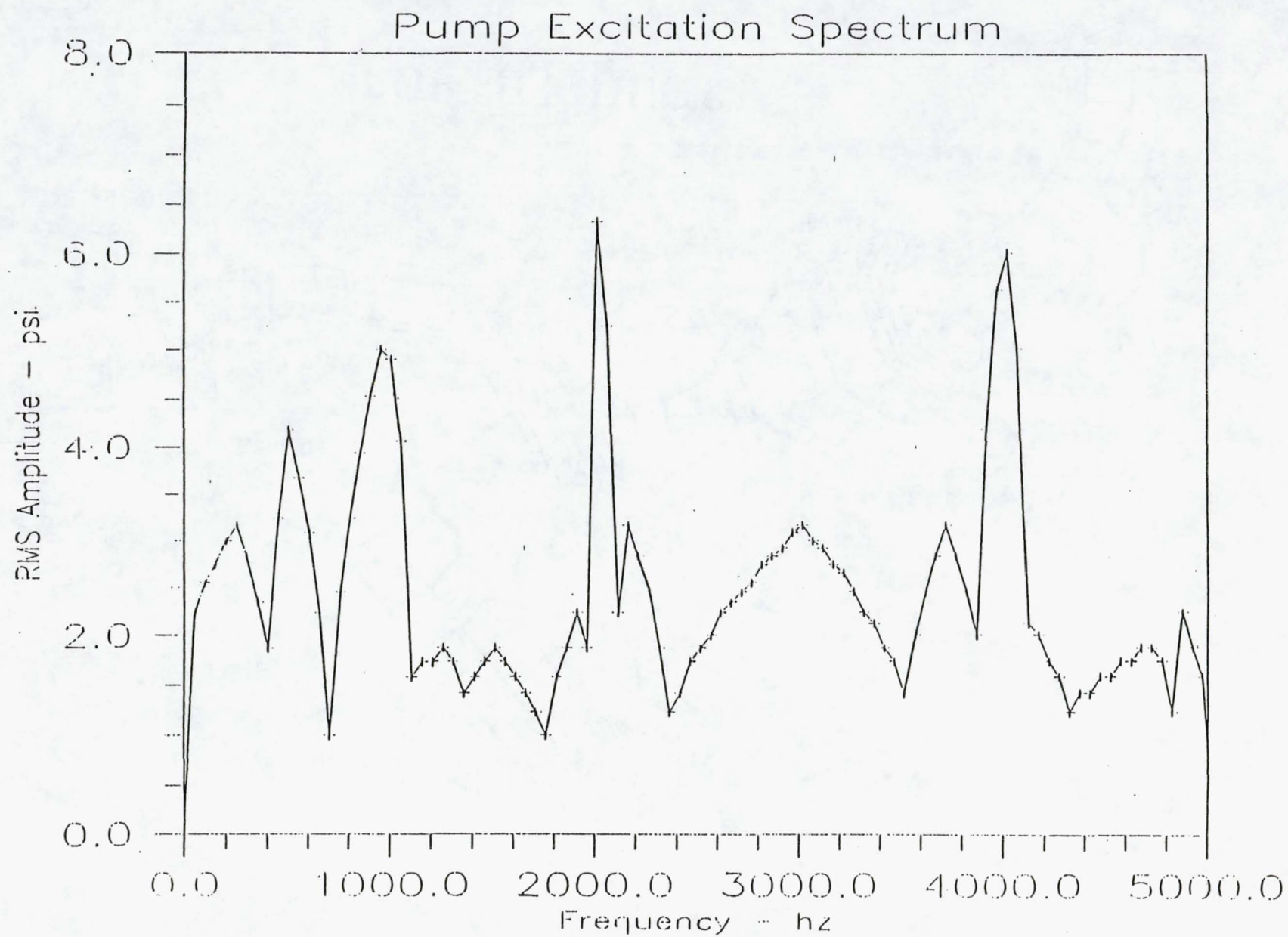


Figure 4.3 HPOTP Pump Noise Excitation Spectrum

2x, 4x and 8x. The HPOTP discharge pressure PSD was obtained from the hot-fire testing measurement. Fig. 4.4 shows the noise source due to elbow flow separation at the elbow, where the Preburner Pump (PBP) inlet duct splits off from the HPOTP discharge duct (see Fig. 4.2).

#### Probabilistic Fluctuating Pressure Load Analysis Results

Probabilistic analyses were performed for several types of excitation. For case #1, a sum-of-sines excitation of uniform magnitude versus frequency was applied at node 1, the HPOTP discharge (see Fig. 4.2). For case #2, a sum-of-sines excitation with magnitudes based on a PSD of measured HPOTP discharge pressure as shown in Fig. 4.3 was applied at node 1. For case #3, the pressure fluctuation from the elbow at node 10 as shown in Fig. 4.4 was the only excitation. For case #4, both excitations from the HPOTP pump and the elbow at node 10 were simultaneously applied to the duct. A sample of the results is presented here. 100 Latin Hypercube Monte Carlo samples were run for each case. Detailed discussion of the four cases is presented in the draft report and will be presented in a future CLS monthly progress report when management review of the draft report is done.

Fig. 4.5 is the amplitude gain of the frequency response function (FRF) for case #1, whose noise source is a uniform excitation applied at the pump end of the duct (node 1). The "error" bars cover the maximum-minimum range of the peaks. The vertical bars cover the amplitude gain ranges and the horizontal bars cover the frequency ranges. There are 10 peaks on the gain curve. Not all sample run have all the peaks. The numbers under the cross bars are the number of the 100 samples that has the peak in their gain curves. Figures 4.6 and 4.7 are the root-mean-square (rms) amplitude spectrum of FRF at node 1 and node 23, respectively for case #4. Both the pump noise and the elbow noise at node 10 were included as the noise sources in case #4. The spectra as shown in Figures 4.6 and 4.7 show more structures than that of Fig. 4.5. In Figures 4.6 and 4.7, the low frequency peak from the elbow excitation is apparent. Features of both excitations can be seen for the medium frequency range. For frequency above 2000 hz or so, where the elbow excitation is tailing off, the FRF spectrum shows strong response to the pump noise.

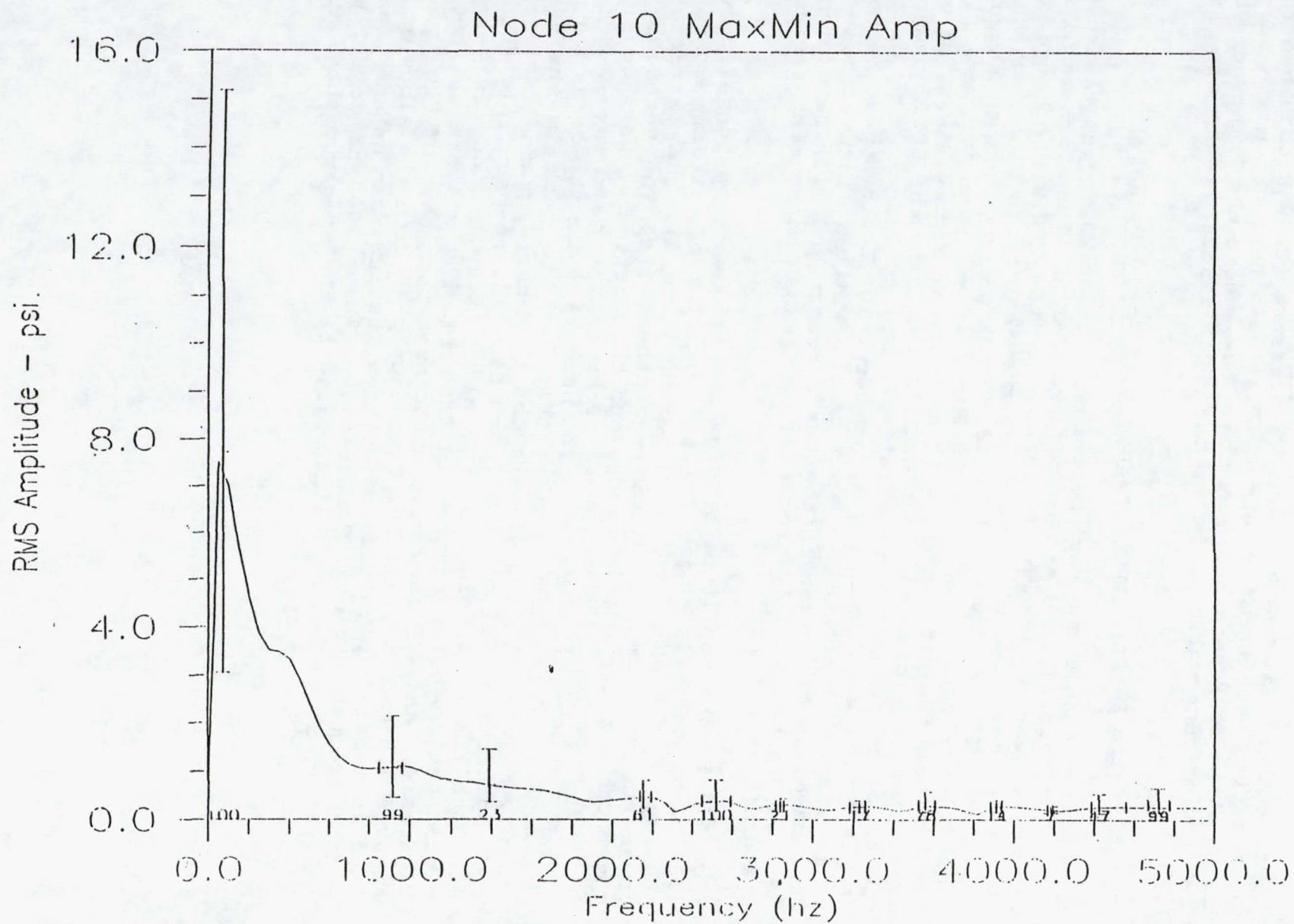


Figure 4.4 HPOTP Discharge Duct Bend Noise Spectrum

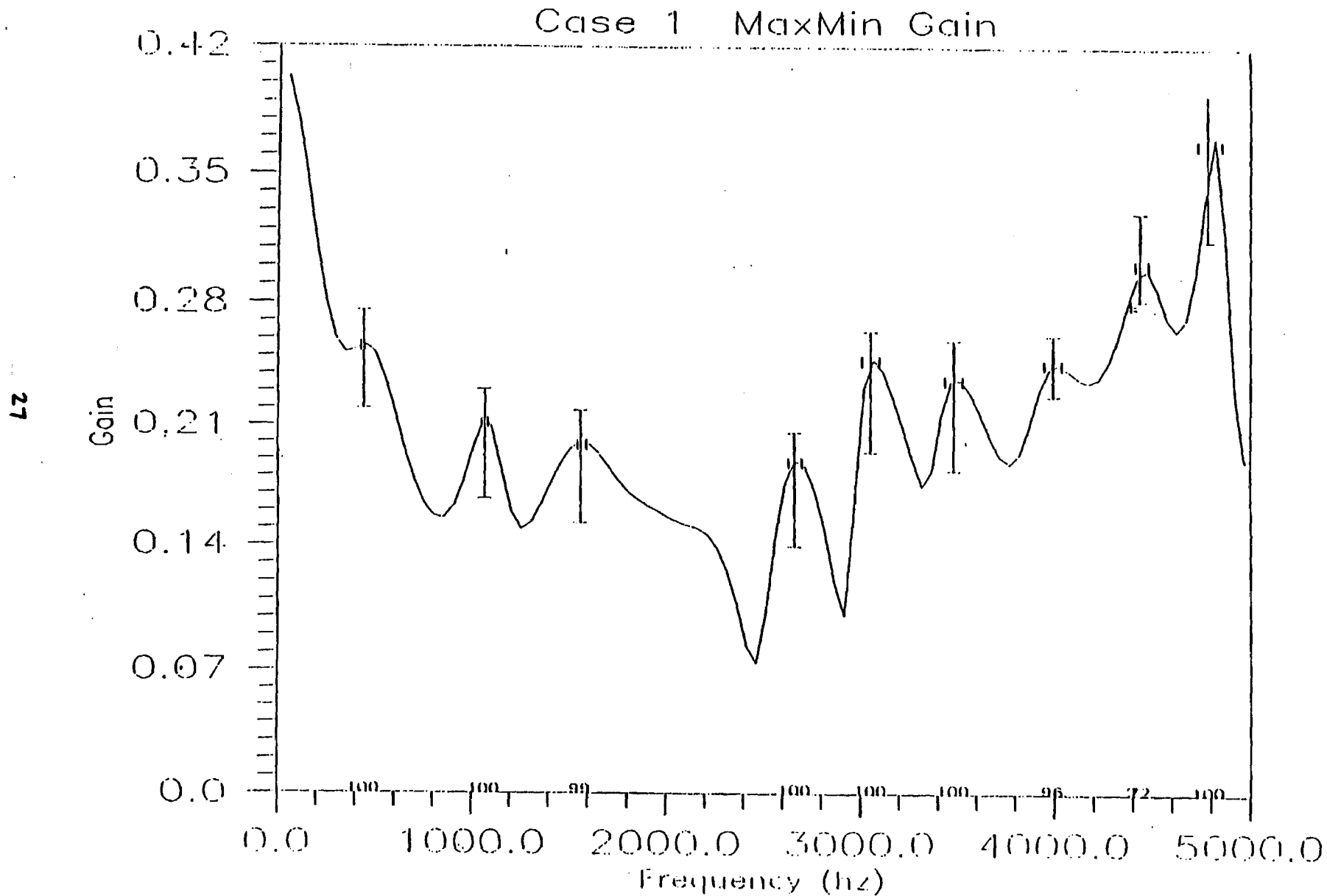


Figure 4.5 Frequency Response Function Gain for  
A Uniform Excitation at Pump End

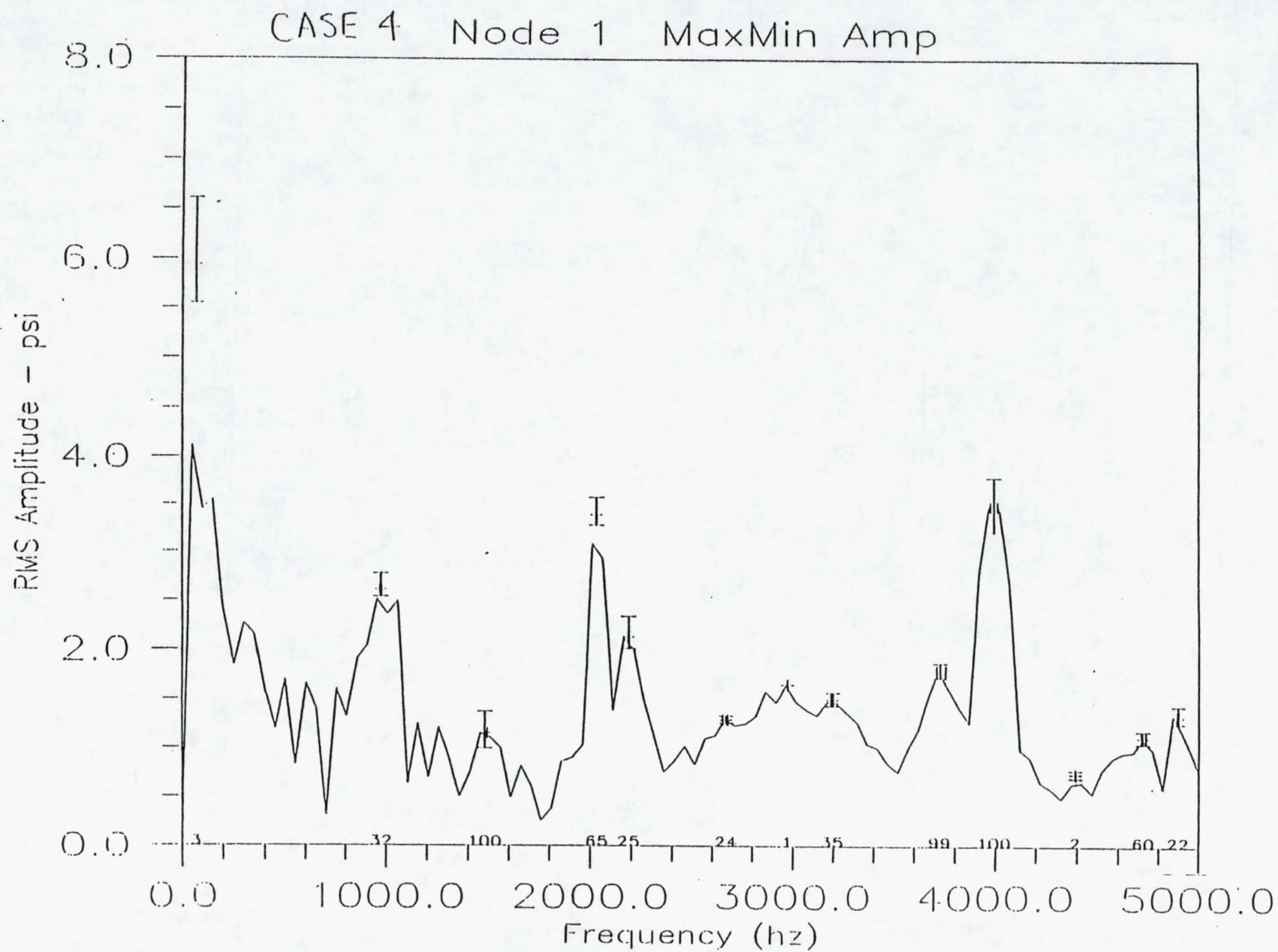


Figure 4.6 Frequency Response Function RMS Amplitude Spectrum  
for Both Pump Noise and Bend Noise Excitations at Node 1

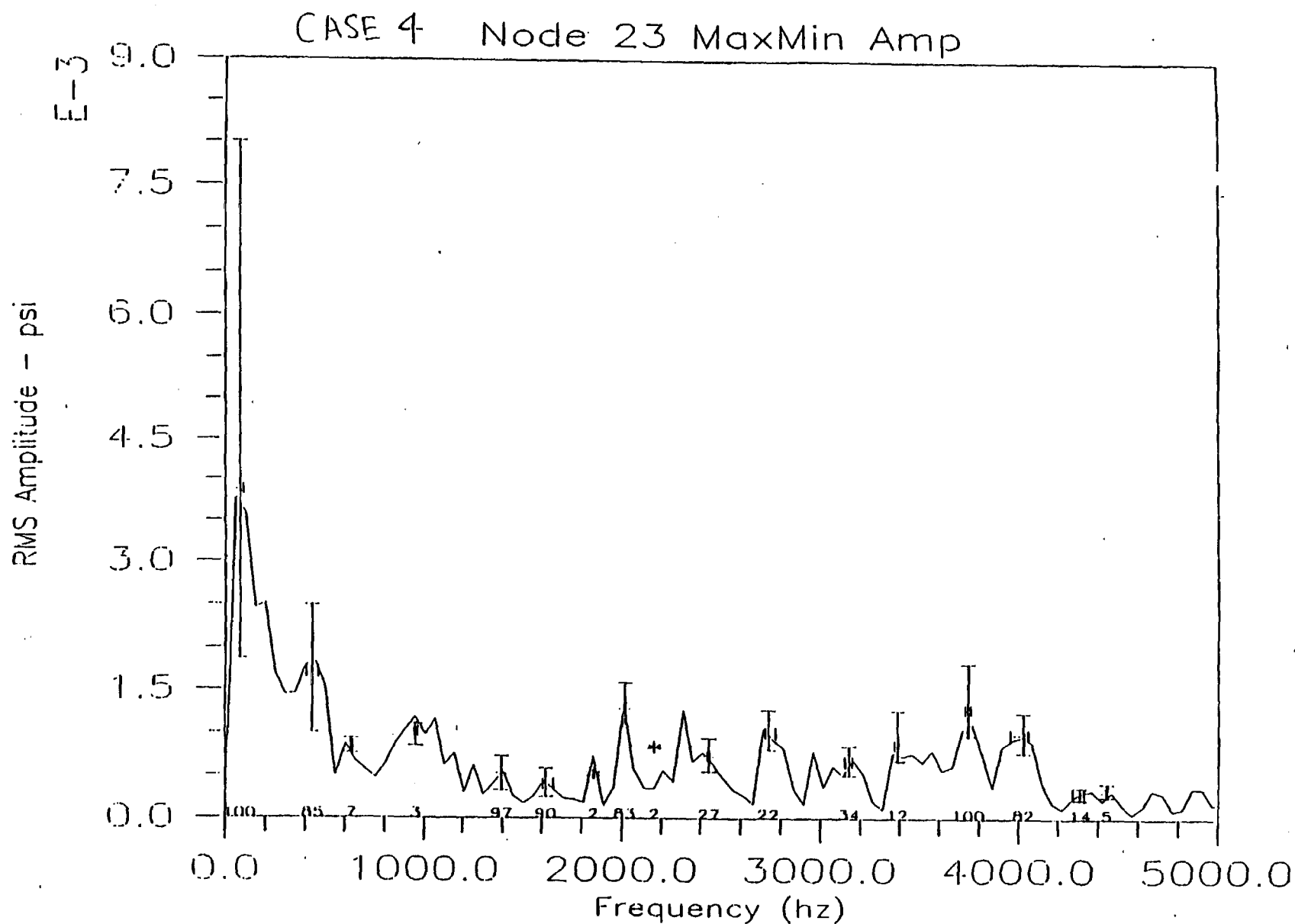


Figure 4.7 Frequency Response Function RMS Amplitude  
Spectrum at Node 23 of Case 4

#### 4.2 CLS Vibration Load Scaling Model

The CLS Vibration Load Scaling Model uses the Composite Load Spectra Component Scaling Criteria (CLS-CSC) to evaluate the scaling constant. The CLS-CSC is a component based scaling criteria evolved from the Barrett criteria. The Barrett scaling criteria scales rocket engine vibrations globally in terms of its thrust and exhaust velocity. A component based scaling has a distinct advantage in that the engine components (such as pumps, turbines, pre-burners, combustors, etc.) primarily vibrate in accordance with local variables such as flowrate and mass of the component.

The CLS-CSC method has provided a simple tool to estimate the broadband vibrational load on rocket engine components at different operating conditions and to estimate the vibrational load on a similar component. More research is warranted to further investigate the methodology.

#### Composite Load Spectra Component Scaling Criteria

The vibration scaling for a new component or a different operating condition is calculated with the following criteria (see Ref. 2.5 and Ref. 4.4):

$$\left( \frac{G^2_{rms}}{P_s} \right)_{NEW} = \left( \frac{G^2_{rms}}{P_s} \right)_{REFERENCE}$$

where,  $G^2_{rms}$  = Vibrational Power  
 $P_s$  = Specific Power

The scaling constant used in CLS-CSC is the specific power. For turbopumps, it can be expressed in terms of the volumetric flowrate ( $Q$ ), the mass of the pump ( $M_p$ ), and a pump geometry lumped parameter ( $K_f$ ).

$$P_s = \frac{K_f * Q^3}{M_p}$$

For combustors, the specific power can be expressed in terms of the mean propellant mass flow rate ( $dm/dt$ ), the mean propellant density ( $\rho$ ), the combustion chamber mass ( $M_c$ ), and the injector faceplate area ( $A_{inj}$ ).

$$P_s = \left( \frac{\dot{m}^3}{M_c * (\rho * A_{inj})^2} \right)$$

#### Results of CLS-CSC for SSME Turbopumps and Combustors

The CLS-CSC vibration scaling model databases employed for SSME turbopumps and combustors are presented in Tables 4.1 and 4.2, respectively. These databases are stored as database VCSC in the CLS knowledge base file.

Table 4.1 CLS-CSC SSME Turbopump Scaling

Turbopump	Mass	$K_r$	Flowrate(lbm/s)		Density(lbm/fl <sup>3</sup> )	
	(lbm)		100%RPL	104%	100%	104%
HPFTP	770	0.00017964	144.32	150.29	4.9587	4.9810
HPOTP	570	0.00166362	1075.12	1116.43	70.2814	70.2119
LPFTP	170	0.0025671	148.45	154.56	4.3536	4.3153
LPOTP	200	0.0009462	1067.15	1108.25	70.2802	70.2449

Table 4.2 CLS-CSC SSME Combustor Scaling

Combustor	Mass	Injector	Flowrate(lbm/s)		Density(lbm/ft <sup>3</sup> )	
	(lbm)	Area(in <sup>2</sup> )	100%RPL	104%	100%	104%
FPB	143	73.9	145.56	152.73	33.766	34.222
OPB	86	35.26	60.64	64.22	27.629	28.371
MCC	470	91.61	1035.42	1078.05	54.747	54.518

The measurements from the big throat SSME test 902-512 are used in this set of analysis results. Fig. 4.8 is the CLS pump scaling result using CLS-CSC. The vibration power  $G^2_{rms}$ 's for the HPFTP, HPOTP, LPFTP and LPOTP are almost lined up into a straight line with a slope of 1 as indicated by the straight line drawn above the data. The same data using Barrett's pump scaling are plotted in Fig. 4.9. By comparison, the CLS-CSC scaling is a better criteria for all SSME turbopumps.

Similar results were obtained for the SSME combustors. Fig. 4.10 shows the CLS scaling for the SSME combustors FPB (fuel preburner), OPB (oxidizer preburner) and MCC (main combustion chamber, measurements at gimbals were used for MCC). Again, the combustors vibration powers are almost lined up into a straight line. Whereas, the vibration powers  $G^2_{rms}$ 's of the SSME combustors using Barrett scaling, as shown in Fig. 4.11 are far apart and the slopes of the combustor data do not quit match a slope of 1.

Figure 4.8 SSME Turbopump Vibration Load CLS Pump Scaling  
Big Throat SSME, Test 902-512

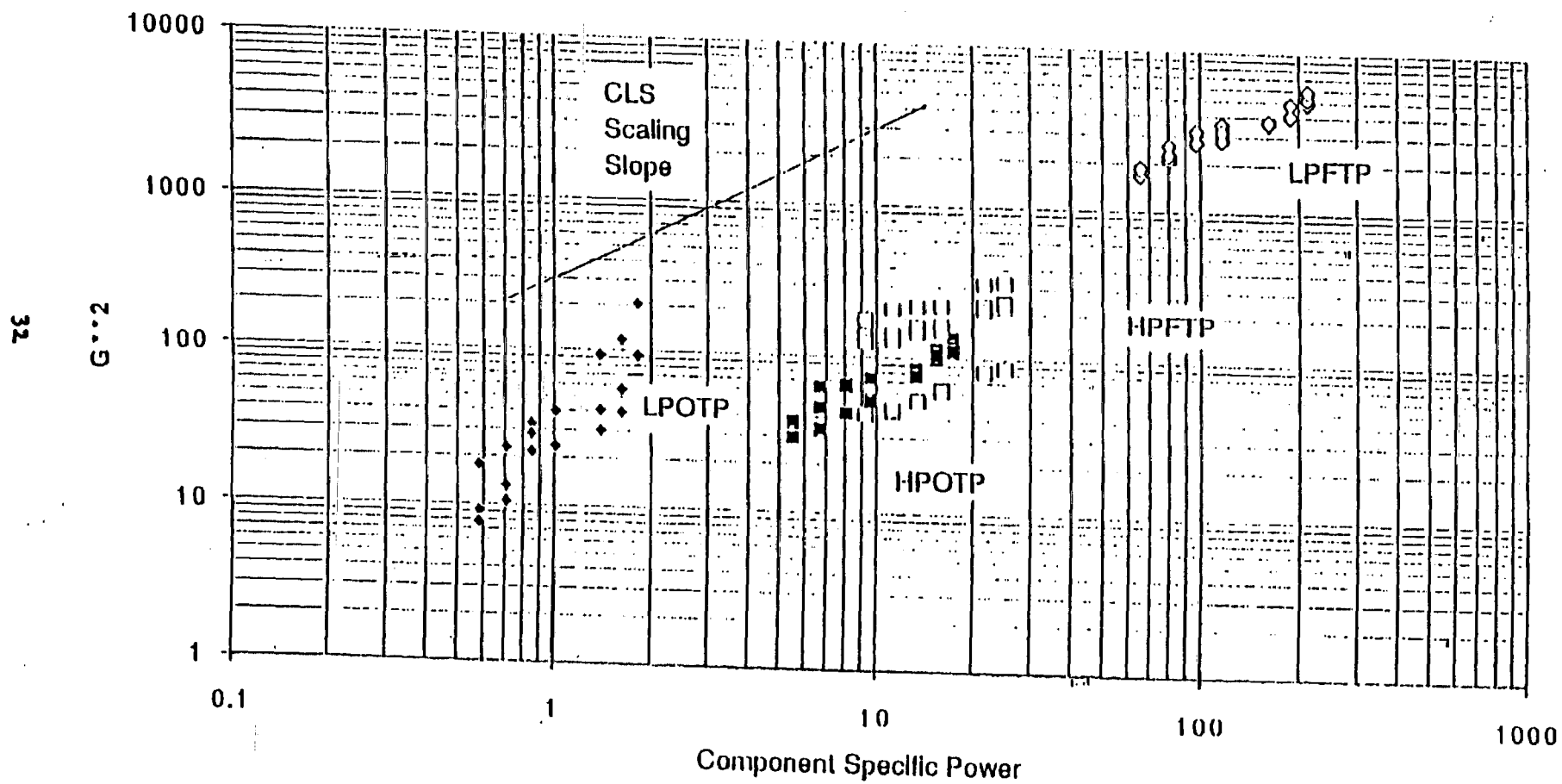


Figure 4.9 SSME Turbopump Vibration Load Barrett Pump Scaling

Big Throat SSME, Test 902-512

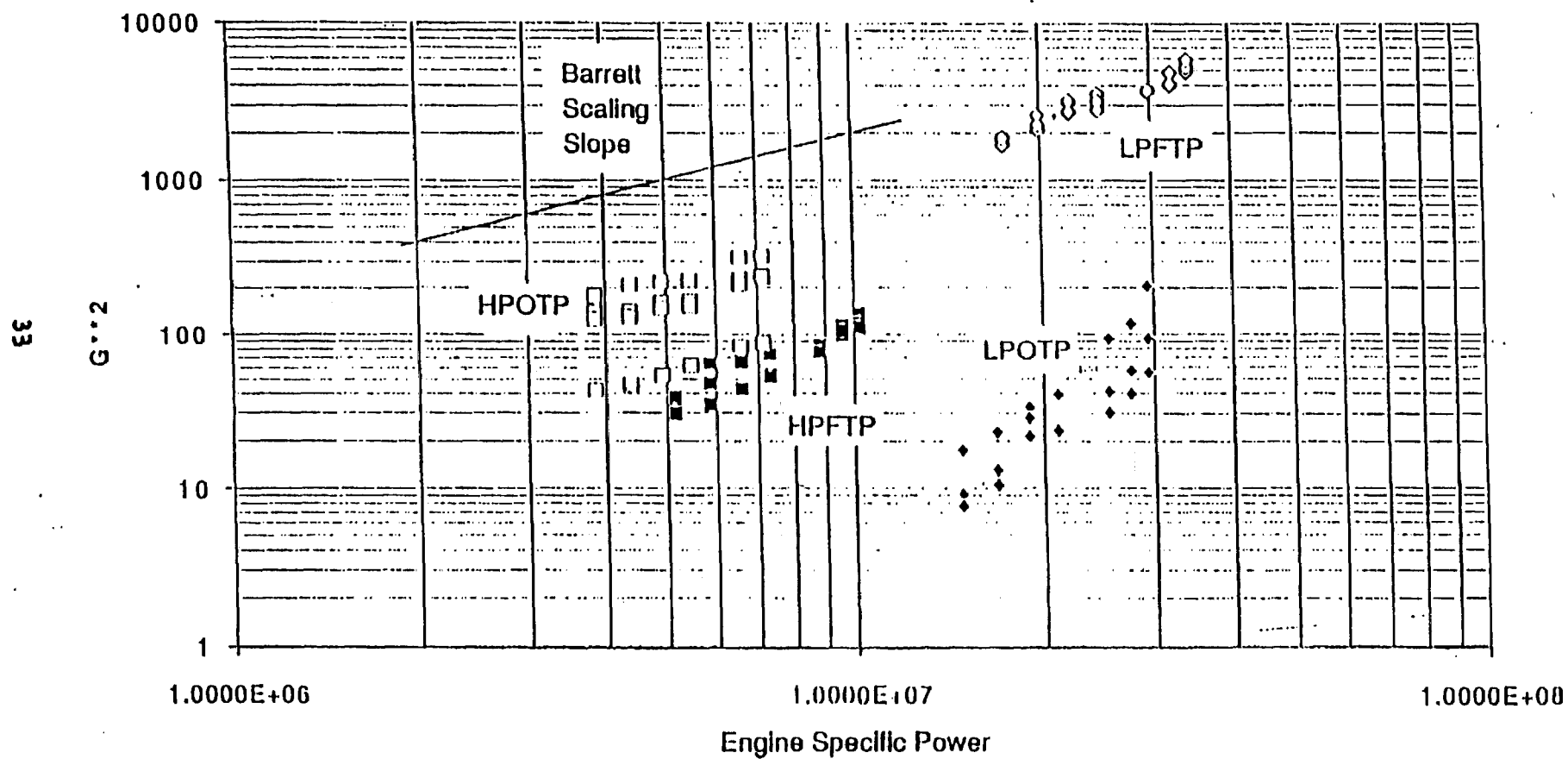


Figure 4.10 SSME Combustors Vibration Load CLS Scaling  
Big Throat SSME, Test 902-512

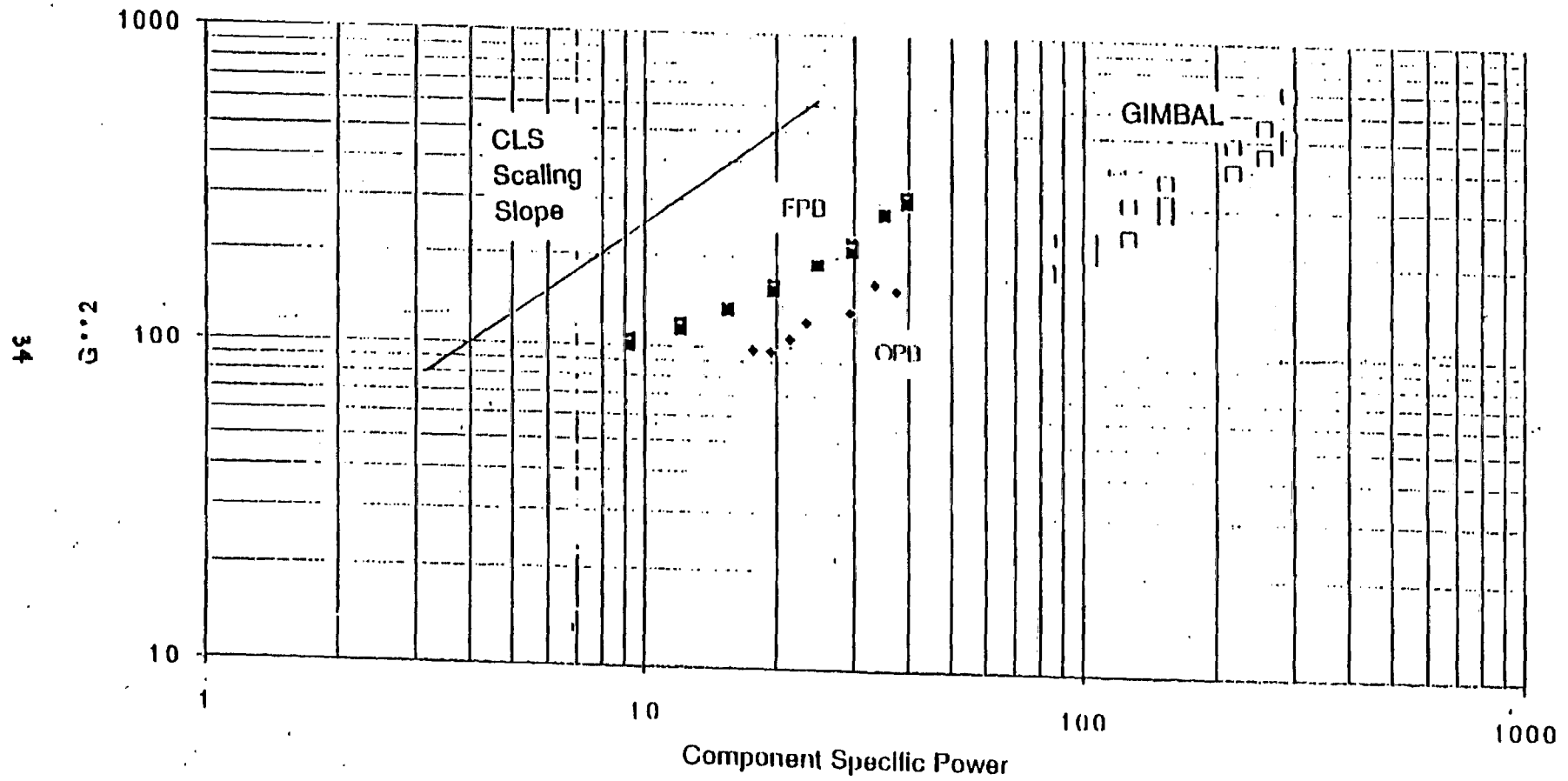
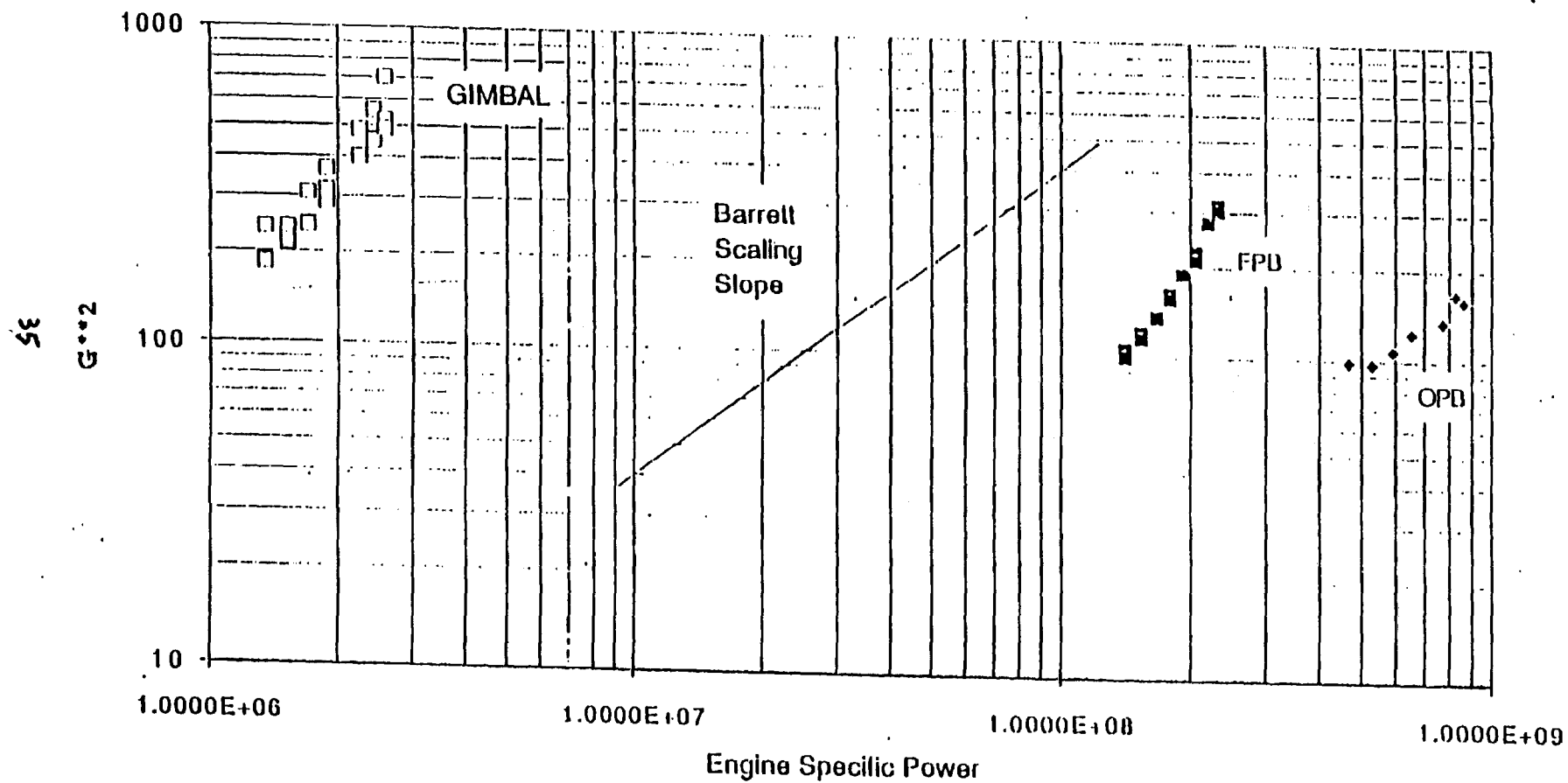


Figure 4.11 SSME Combustors Vibration Load Barrett Scaling

Big Throat SSME, Test 902-512



#### 4.3 References

- 4.1) W. D. Romine, IL dated 2 December 1992, "Influence Coefficients for HPFT Second Stage Blade Transient Thermal Model", ATU 92-129-072, Rocketdyne, Rockwell International
- 4.2) T. H. Tran, IL dated 2 December 1992, "Thermal analysis of SSME HPFT Second Stage Blade in Support of A Composite Load Spectra Modeling Study", ATU 92-129-055, Rocketdyne, Rockwell International
- 4.3) W. D. Ewing, IL dated 8 June 1992, "Probabilistic Acoustic Analysis of SSME High Pressure Oxidizer Turbopump Discharge Duct", 2128-0116, Rocketdyne, Rockwell International  
Rocketdyne, Rockwell International
- 4.4) S. A. Harvey, IL dated 4 September 1990, "Alternate Turbopump Vibration Environment Estimate", IL 0128-0128, Rocketdyne, Rockwell International
- 4.5) Iman, R. L. and M. J. Shortencarier, "A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models," NUREG/CR-3624, SAND83-2365, March 1984

## 5.0 CLS APPLICATIONS

In the previous contract, a CLS correlation field formalism was developed to provide a theoretical basis of linking CLS to other probabilistic analysis applications. The CLS correlation field formalism can be used to synthesize correlated probabilistic load set and pass the correlated load distribution functions to the application code that needs them. An approximation of the CLS correlation field formalism using "marginal" distributions was developed and applied to the LOX Post probabilistic structural analysis (Ref. 5.1). Other applications of the CLS technology include the probabilistic structural analysis of a space propulsion system turbine blade (Ref. 5.2), the probabilistic failure analysis of a space propulsion system main combustion chamber liner (Ref. 5.3).

In this contract, new methods were developed for the applications of the CLS technology. Two methods were developed, one for each of the applications presented below. The two methods are similar. The first method was implemented in the CLS expert system rule module RBSCLM. Thus it is called the RBSCLM (Rule Based SCLM) method. The method requires CLS to evaluate the load values needed by the application, save the load information and values in a file and send it to the application. Implementation and application of this method to a fatigue life prediction/evaluation of a space propulsion system injector element (Ref's 5.4 - 5.5) are described in section 5.1. The second method was implemented in the CLS expert system rule module RBPSAM. Thus, it is called the RBPSAM (Rule Based PSAM) method. This method requires that a subset of the CLS engine load module be embedded in the application code. The RBPSAM module will prepare a CLS load database file providing the needed load information and data to the engine load module subset to evaluate the loads on-line within the application code. Application of this method to the probabilistic design analysis of a space propulsion system main combustion chamber liner (Ref. 5.6) is presented in section 5.2.

### 5.1 Structural Component Life Model (SCLM)

#### 5.1.1 Introduction

The function of the load model is to provide structural system loads and component loads for the life evaluation/prediction of the component. These loads should be evaluated at the selected time slices of an engine mission at the appropriate power level and operating condition. The load simulation requires an engine model that can properly simulate the engine operation of the missions. The Composite Load Spectra (CLS) expert system load simulation program has the capability to simulate the engine operation and evaluate the component loads. The approach is to employ the CLS

code to supply the load information and data to the life evaluation model by generating a user interface file that contains the requested information.

The Composite Load Spectra program is a knowledge-based system for the component load simulation of a space propulsion system (Ref's 5.7, 2.2-2.5). Its main purpose is to synthesize rocket engine deterministic and probabilistic loads for a flight or test mission. CLS has the facilities to generate and manage the databases, and implement the expert system queries to interface with users in the knowledge domain of rocket engines. CLS has already in place a knowledge base of extensive engine loads and primitive variables and a collection of load simulation tools. In the tool set of the CLS load expert system LDEXPT, there is an engine system model that can synthesize the deterministic system loads suitable for component life evaluations/predictions. This model was implemented in an expert system rule module RBSICM (Rule Base System Influence Coefficient Model). In LDEXPT terminology, a rule module is a module of computer code that can perform an interactive consultation session with a user to carry out certain task. For the structural component life model project, a rule module RBSCLM (Rule Base Structural Component Life Model) was implemented in the CLS load expert system to synthesize the engine system loads and pass the load information and data to the component life evaluation computer program.

RBSCLM was implemented for an application of probabilistic structural analysis in computing the fatigue damage of a space propulsion system injector element. The analysis considers the variations in static and dynamic loads, the uncertainty in structural damping, and the scatter in material fatigue resistance. The loads requested for the fatigue life evaluation include (1) the component loads: LOX post fuel side hot gas flowrate and temperature, hot gas mixture ratio, total hot gas flowrate, LOX pressure at the LOX post threaded region, and main injector LOX flowrate; (2) the component local variables: the hot gas heat transfer film coefficient factor, the coolant heat transfer film coefficient factor, the Haynes 188 conductivity (K) factor, and hot gas density; (3) engine system dependent loads or variables: the high pressure fuel turbopump (HPFTP) turbine flowrate, the HPFTP turbine discharge temperature, HPFTP turbine hot gas mixture ratio, the high pressure oxidizer turbopump (HPOTP) pump discharge temperature, HPOTP turbine flowrate, HPOTP pump discharge velocity, the main combustion chamber (MCC) injector end pressure, and MCC hot gas injector pressure and (4) engine system primitive variables or independent load variables: HPFTP turbine flow coefficient, HPFTP turbine efficiency, HPFTP pump efficiency, HPOTP turbine flow coefficient, HPOTP pump efficiency, engine oxidizer inlet temperature, MCC throat diameter and MCC  $P_0$  measurement error, etc. These loads are evaluated with the CLS engine influence model and component load object functions and they are then sent to other modules (thermal analysis and structural response modules) of the life evaluation software system to continue the analysis.

### 5.1.2 The RBSCLM Rule Module

The defined tasks for the RBSCLM rule module are as follows:

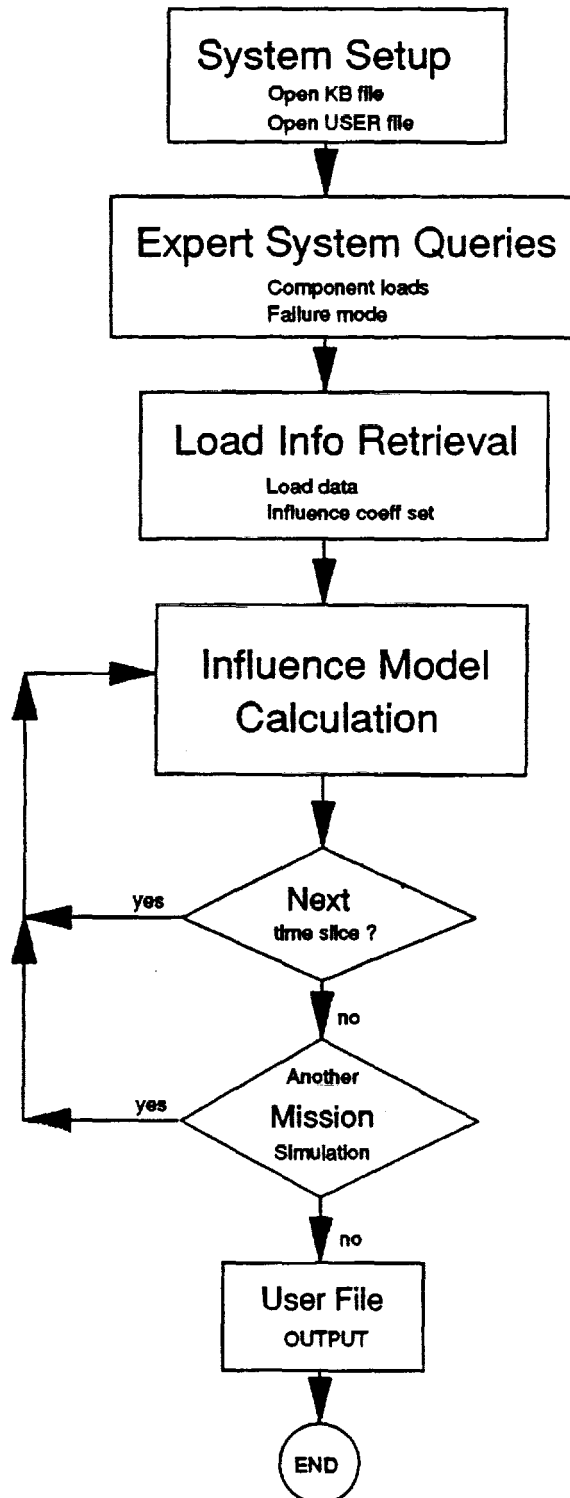
- (1) Query user for component and load selections;
- (2) Retrieve system load information and data;
- (3) Select primitive variables and retrieve their load data and influence coefficient sets;
- (4) Perform influence model calculations for different engine power levels and evaluate the component loads;
- (5) Generate a SCLM user interface file that pass all relevant information and data to the life evaluation module.

The flow chart of this process is shown in Fig. 5.1. In task (1), the rule module prompts user to select a component, its location for the analysis and its failure mode. Once the user finishes the selection, the code performs task (2), going to the databases and retrieving the requested component loads and related system loads. In this task, the rule module calls on other existing CLS rule modules to retrieve the component local loads and system dependent loads. Next, it calls on another rule module in task (3) to retrieve system independent loads and associated influence coefficient sets based on the list of dependent loads obtained in task (2) and carry out the influence model evaluation in task (4). The influence model calculation is repeated for as many time slices as the user requested. When the computation for a mission is complete, the system will prompt the user for the next mission. When all simulations are complete, a SCLM user interface file is written that contains the load information and the calculated system load values. A sample run print-out of RBSCLM generated by the SUN OS's "script" file command is included as Appendix A.2 to show the detail process. The user file generated is shown in Appendix A.1.

In tasks 2, 3 and 4, RBSCLM calls on other existing rule modules to help carrying out the jobs. The RBTHCL module retrieves the component local loads. The RBSICM module performs the complete tasks for an engine influence model evaluation. It first calls on rule module RBLDEP to retrieve automatically the system dependent loads and then calls on rule module RBLIDP to retrieve the primitive variables (or independent loads) either manually if so chosen by the user or automatically by the expert system. The expert system has the knowledge to select the most influential independent loads or primitive variables for evaluation. It then prompts user for the values or changes of the independent loads and calculate the independent load values. With all load data at hand, the RBSICM then calculates the system dependent loads using the influence model. With the calculated system dependent loads, RBSCLM next calls the component load object functions (see Appendix B) to evaluate the component loads at the location of interest. These evaluated component loads are the ones used in the damage calculation.

Load descriptions more detail than the cryptic 8-characters load

Figure 5.1 CLS Structural Component Life Modeling Process



names are available in the expert system. They are used to generate an expert system log file LOGFIL. A sample LOGFIL for the session presented in Appendix A.2 is included as Appendix A.3. This file provides a record for the process carried out during the consultation session. To move the load descriptions to a user interface file, they are posted on the OUTPUT-BLACK-BOARD during the process. The RBSCLM module then collects them and the calculated data to generate a user interface file.

### 5.1.3 The CLS Databases

The rule module RBSCLM obtains the necessary load information and data from five different databases. They are the databases SCLM (structural component life model), LDEP (system dependent loads), LIDP (system independent loads), LCTH (component loads and component local loads), and INFC (influence coefficient set).

The SCLM database provides a list of system dependent loads and component local loads correspondent to the selected component load failure mode. The following database record is for the LOX post threaded location low cycle fatigue failure:

<u>Database-FIELD</u>	<u>VALUE</u>	<u>Comment (not in database)</u>
CMFN-ID	6	Component ID for LOX post
CMFN-LOC	THREAD	Threaded location
C-LD-ID	45	Load ID for low cycle fatigue
C-LD-NA	LPTHRLCF	Load name limited to 8 char.'s
LD-TYPE	TEN	Load type
LDEP1-ID	6048	Composite dependent load ID
LDEP2-ID	6029	Same as above
LDEP3-ID	6072	Same
LDEP4-ID	6020	Same
LDEP5-ID	6047	Same
LDEP6-ID	6017	Same
LDEP7-ID	6091	Same
LDEP8-ID	6531	Component local load ID
LDEP9-ID	6530	Same as above
LDEPA-ID	6536	Same

The first three fields: CMFN-ID, CMFN-LOC and C-LD-ID are the keys of the database. Once their values are determined by a user or the expert system, the corresponding record will be retrieved by the CLS database system.

The dependent load database LDEP provides the engine system dependent load information and data. With the dependent load ID from the SCLM database record, the correspondent dependent load database record can be retrieved. The following is the dependent load record with load-ID 48:

<u>Database-FIELD</u>	<u>VALUE</u>	<u>Comment (not in database)</u>
LDEP-ID	48	System dependent load ID
LD-NAME	HPFT-FL	HPFTP turbine flowrate
MEAN	158.92	mean value (lbm/s)
COV	0.01	coefficient of variation
P3	0	not used
DIST	NORMAL	normal distribution
NE-COEF1	-21.4	nominal engine coeff. $b_{10}$
NE-COEF2	180.03	nominal engine coeff. $b_{11}$
NE-COEF3	-25.126	nominal engine coeff. $b_{12}$
NE-COEF4	25.427	nominal engine coeff. $b_{13}$ see equation (1).

Similarly the independent load database LIDP provides independent load information. For example, the independent load record with load-ID 58 is as follow:

<u>Database-FIELD</u>	<u>VALUE</u>	<u>Comment (not in database)</u>
LIDP-ID	58	System independent load ID
LD-NAME	HPFT-FLC	HPFTP turbine flow coefficient
MEAN	1.0125	mean value
COV	0.01	coefficient of variation
P3	0	not used
DIST	NORMAL	normal distribution
NE-COEF1	1.0125	nominal engine coeff. $a_{10}$
NE-COEF2	0	nominal engine coeff. $a_{11}$
NE-COEF3	0	nominal engine coeff. $a_{12}$
NE-COEF4	0	nominal engine coeff. $a_{13}$ see equation (1).

The database LCTH provides load information on the component loads and component local loads. This database has two key fields CMPN-ID and C-LD-ID. Both key values, the component ID and the load ID, are required to identify a record in this database. For example, the hot gas density record is as follow:

<u>Database-FIELD</u>	<u>VALUE</u>	<u>Comment (not in database)</u>
CMPN-ID	6	Component ID for LOX post
C-LD-ID	35	hot gas density load-ID
C-LD-NA	HG-DENS	LOX post hot gas density
MEAN	0.68	mean value
COV	0.05	coefficient of variation
P3	0	not used
DIST	NORMAL	normal distribution
NE-COEF1	0	not used
NE-COEF2	0	not used
NE-COEF3	0	not used
NE-COEF4	0	not used

The influence coefficient database INFC provides the influence coefficient constants  $c_{ji}$ 's for calculating the influence coefficients  $IC_{ji}$  of equation (1). It uses the system dependent load-ID and independent load-ID as the key fields. An example record of the influence coefficient database for dependent load 48 and independent load 58 is as follow:

<u>Database-FIELD</u>	<u>VALUE</u>	<u>Comment (not in database)</u>
LDEP-ID	48	Dependent load-ID
LIDP-ID	58	independent load-ID
INFL-C1	0.41872	influence coeff. set $c_{j1,0}$
INFL-C2	0.09119	influence coeff. set $c_{j1,1}$
INFL-C3	0	influence coeff. set $c_{j1,2}$
INFL-C4	0	influence coeff. set $c_{j1,3}$
GAIN65	0.00478	gain at 65% power level
GAIN90	0.00500	gain at 90% power level
GAIN100	0.00510	gain at 100% power level
GAIN104	0.00514	gain at 104% power level

#### 5.1.4 CLS Implementation

The rule-based management system RBMS that manages and run the rule modules was implemented on a ROCKETDYNE SUN workstation network. To run an interactive session of the load expert system after logging on to the SUN network account, just type in 'ldrbms40' to start the program (the upgraded object module as of January 1993 is 'ldrbms52'). A sample RBSCLM session was recorded in a log-file (see Appendix A.2) with SUN OS's "script" command. The log-file was heavily commented to describe the details of the process.

For an interactive session, the expert system prompts and queries users for all input that the program needs to perform the tasks. The expert system queries are fairly straightforward with possible answers and options posted following the questions. The rule module prompts which are specific to the rule module itself are expecting simple 'Yes' and 'No' answers, or numbers. The queries and prompts together with answers are documented in the log-file (Appendix A.2).

The load expert system program can also be run in batch mode using UNIX input redirection facility. An input file is required. It can be easily constructed by putting into it all user's responses to the expert system's queries and prompts, one response per line. A sample input file for a RBSCLM run is presented in Appendix A.4. To run the program in batch mode, enter on a command line:

```
ldrbms40 < input-file-name
```

The RBSCLM rule module is very flexible in getting loads. More than one component load can be selected in a run (of the code), see page 7 of Appendix A.2. Each component load has its own list of component local loads and system dependent loads. The expert system combines these loads into a single list. The same loads would not appear twice in the list. Users can also add component local loads to the list, see page 9 of Appendix A.2.

The expert system queries are fairly user-friendly. Possible answers and/or options are posted following the questions. In choosing the response, enter the integer (if there is one) that is in front of the answer you would like to select or enter the exact character string normally in upper case that is in front of the desired answer. For example, there are three queries in RBSCLM for the selection of the component load failure mode. The first query as shown on the CRT screen is:

```
Please select a component ID
1   HPFT
5   HGM Fuel Center Transfer Tube
6   LOX Post
7   LOX Post region B
8   LOX Post region C
9   HGM Oxidizer Transfer Duct
10  HPOP Discharge Duct
11  LOX Post Oxidizer Side
```

To response, a user should select an integer from the list such as 6 for LOX Post. The second query is:

Which is the location of the COMPONENT that you want to analyze ?

Please enter the key word: THREAD, IN-WELD

THREAD : Threaded location

IN-WELD: Inertia Weld location

To response, a user should enter the text string of either THREAD or IN-WELD. The third query is:

What is the FAILURE MODE that you want to consider ?

45 LCF (Low Cycle Fatigue) Damage

46 HCF (High Cycle Fatigue) Damage

To response, a user should enter an integer of either 45 or 46.

These and other query panels are stored in the problem text file LDKBPTF. Each query panel is activated by a "button" or query attribute. The query panel can be easily modified by editing the problem text file.

#### 5.1.5 Summary

The CLS load expert system module 'ldrbms' was successfully implemented on a SUN workstation network. The CLS extensive load knowledge base, its facilities and simulation tools have facilitated the development of the structural component load model (SCLM). Incremental development and extending the SCLM model to other components will be simple.

The rule module RBSCLM has performed as designed. It retrieves all relevant load information and evaluates the system loads with the influence model. It generates a user interface file to pass the calculated load values and load descriptions to the component life evaluation program. This saves analysts' times and efforts to gather the load information and data and automates the load modeling process.

## 5.2 CLS Load Module and Database for a Space Propulsion Structure Component MCC Liner Life Evaluation

A probabilistic approach to the evaluation of fatigue damage requires as input a set of probabilistic component structural response variables. The component response variables are functions of engine system dependent loads and/or component local variables. The component local variables are related to component material properties and geometry factors. They are independent variables. However, the system dependent loads are dependent of engine hardware characteristics (or hardware parameters) and inlet operating conditions (for convenience, they are collectively named the primitive variables or the engine independent "loads"). To obtain a set of correlated component structural response variables, one solution is to sample the primitive variables and the independent local variables and propagate the variations to component loads through an engine model. The CLS engine model can be embedded in the application program. This setup is illustrated in Fig. 5.2. It is a very general scheme of linking the CLS technology to other applications. The direct hookup between the engine load module and the application program assures that the correlation of the response variables is preserved in the application code.

### The Embedded Deterministic Engine Load Module CLSICM

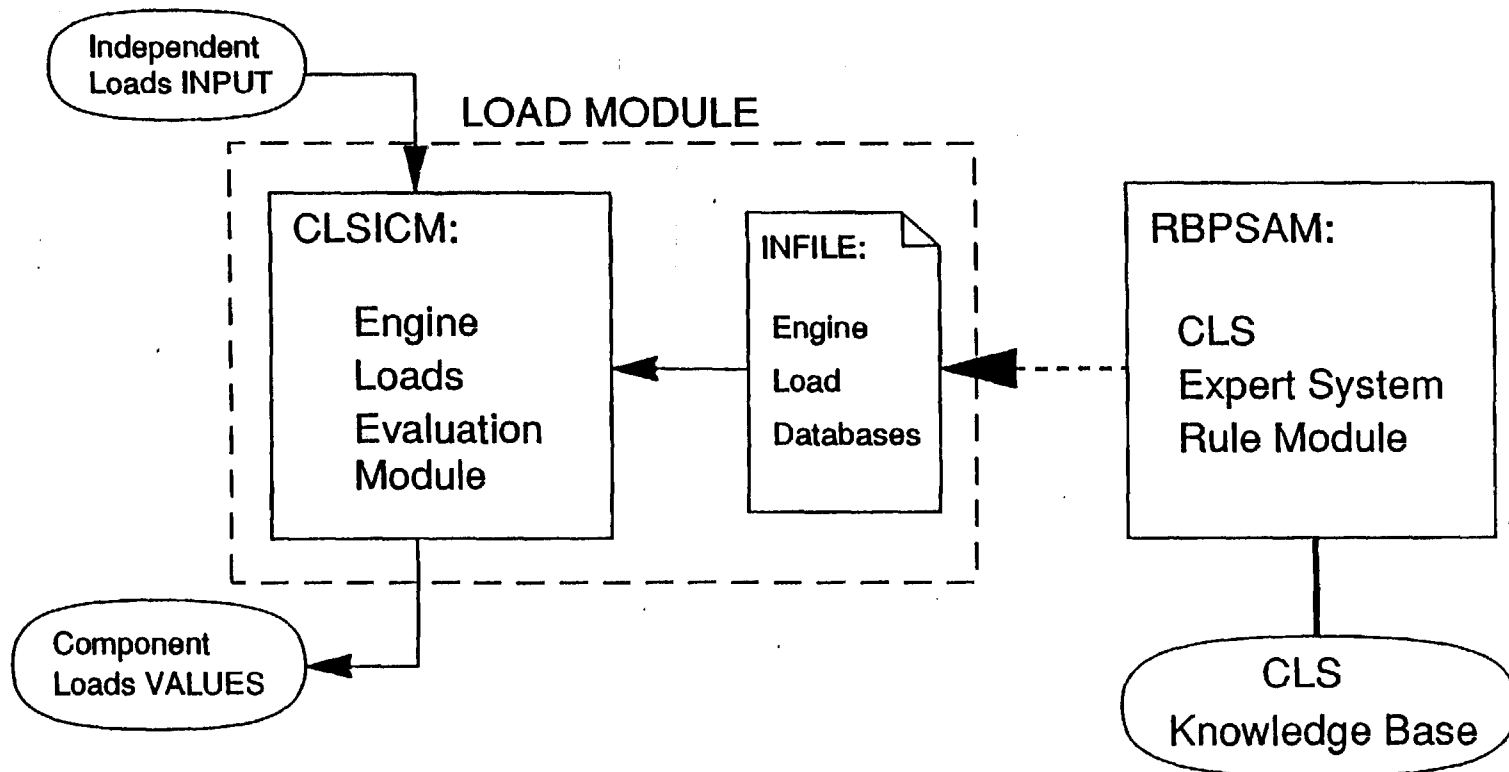
An embedded Composite Load Spectra (CLS) load module CLSICM was linked to the life evaluation code to supply the thermal environment condition loads which are required to perform the thermal analysis of the MCC liner. The thermal environment loads are functions of the flow condition and the thermal properties and geometry of the liner. While the thermal properties and the geometry of the liner can be treated as independent variables, the flow is correlated to the engine operation and performance. The CLS load module provides just this kind of linkage between a component environment model of a space propulsion structural component and an engine performance model.

The CLSICM module performs component load calculation using the coupled engine model. The coupled engine model consists of an engine influence model for system model and many component load models. The engine influence model calculates system dependent loads and the component load model calculates the component loads with load object functions. The CLSICM module carries the following process: (1) CLS load databases input, (2) engine influence model calculation, and (3) component load evaluation.

The calling program sends a list of requested component loads and a list of point values of the independent primitive variables to

Figure 5.2 CLS Application Embedded Load Module

CALL from  
Application Programs



the embedded load module and the load module returns the point values of the requested component loads and/or system loads. Table 5.1 lists the component loads, component local independent loads, and engine primitive variables used in the MCC liner load simulation.

Table 5.1 CLS Load Variables

<u>Load Type</u>	<u>Load Name</u>	<u>Description</u>
Component Loads	MCCLNTWG	MCC liner hot gas wall temperature
	MCCLNTCN	MCC liner wall temperature at corner
	MCCLNTMN	MCC liner minimum wall temperature
System dependent loads	MCC-IEP	MCC chamber pressure
	MCC-C-PO	MCC coolant discharge pressure
	COO-FL	MCC coolant flow factor
Component local loads	COOL-GF	Coolant heat transfer film coeff.
	HG-GF	Hot gas heat transfer film coeff.
	HOT-SPOT	Local hot spot factor
	COOL-ENH	Coolant enhancement factor
	LN-KF	MCC liner conductivity
	HG-W-THN	Hot gas wall thickness
Engine primitive Variables	ENG-FFLE	Engine fuel flowmeter error
	MCC-PCER	MCC P <sub>c</sub> measurement error
	LPFT-NA	LPFTP turbine nozzle area
	HPFT-EM	HPFTP turbine efficiency multiplier
	MR	Commanded mixture ratio
	F-PI	Fuel inlet pressure
	O-PI	Oxidizer inlet pressure
	F-TI	Fuel inlet temperature
	O-TI	Oxidizer inlet temperature

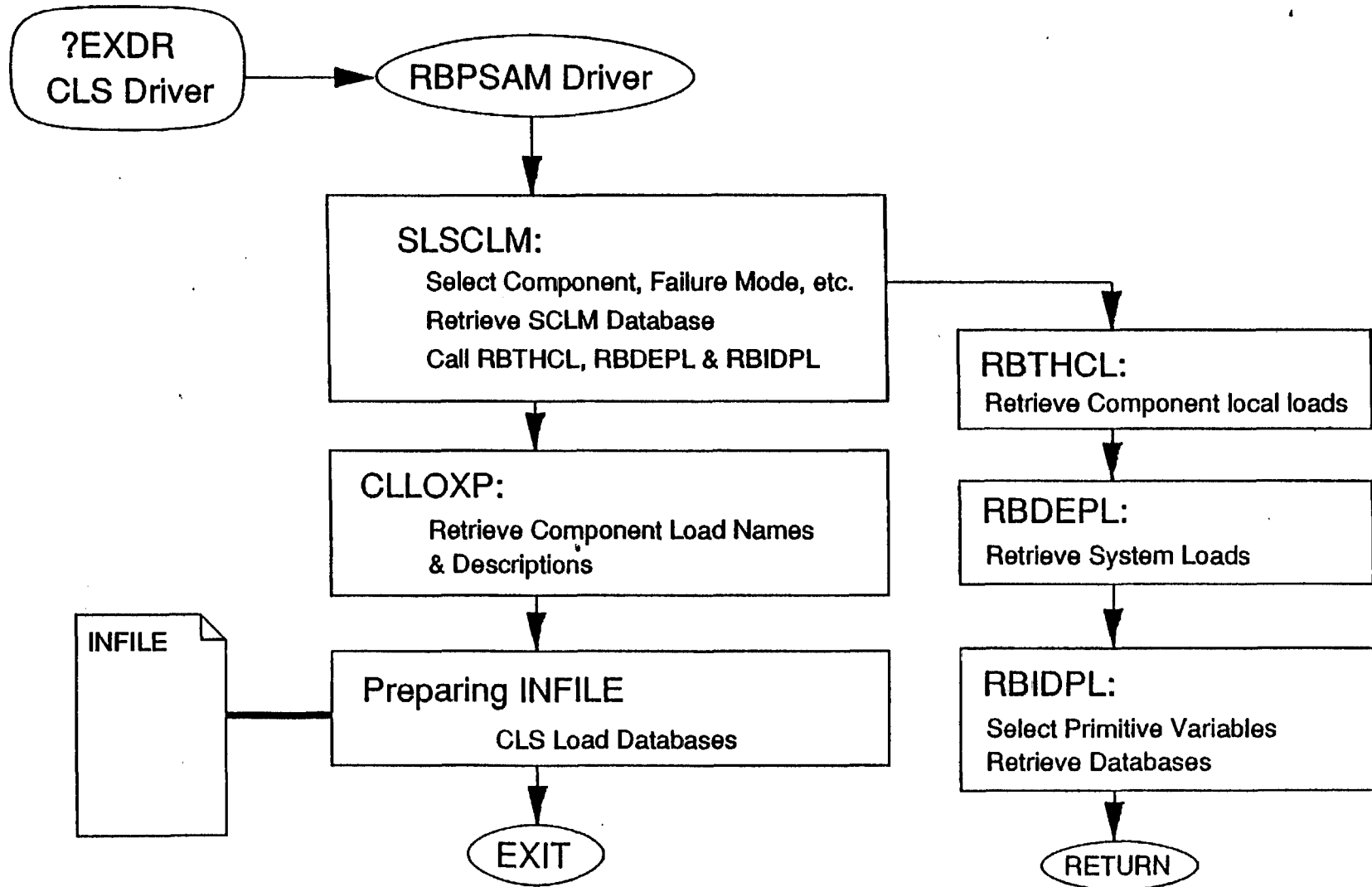
#### The Intelligent Database Module RBPSAM

The required engine load databases for the load module is input from the INFILE as illustrated in Fig. 5.2. An INFILE for the structural component Main Combustion Chamber liner life prediction analysis is presented in Appendix A.5. INFILE can be prepared manually or better yet with the CLS rule module RBPSAM. The RBPSAM module is a rule module of the CLS expert system to carry out specifically the task of retrieving the load information and databases for performing a component load evaluation by the CLSICM module.

The process of RBPSAM is shown in Fig. 5.3. It first consults with the user to find out the requested component and component loads, the time intervals and power levels for the analysis. It then proceeds based on its knowledge base to retrieve the required system dependent loads and component local loads, select the most influential primitive variables and retrieve their load information from the knowledge base. There are many data, such as the means and coefficients of variation of the loads and the influence coefficient sets for the engine system model, needed for the load simulation. The intelligent database system provides the service, save users from the tedious task of gathering data and improve productivity.

This application demonstrates that the CLS technology can be easily employed in many probabilistic analysis applications. The linking method to other application provided here is very efficient. The compact engine load module can be conveniently embedded in an application program. Whereas, the expert system module RBPSAM utilizes CLS's user interface facility and the full load knowledge base to supply the load information and databases.

Figure 5.3 CLS RBPSAM Rule Module



### 5.3 References

- 5.1) Newell, J. F., K. R. Rajagopal, H. W. Ho and J. M. Cunniff, April 1990, "PROBABILISTIC STRUCTURAL ANALYSIS OF SPACE PROPULSION SYSTEM LOX POST," AIAA 31st Structures, Structural Dynamics and Materials Conference, Long Beach, California
- 5.2) Newell, J. F., K. R. Rajagopal and H. Ho, April 3-5, 1989, "PROBABILISTIC STRUCTURAL ANALYSIS OF SPACE PROPULSION SYSTEM TURBINE BLADES," AIAA 30th Structures, Structural Dynamics and Materials Conference, Mobil, Alabama
- 5.3) Newell, J. F., K. R. Rajagopal, H. Ho and J. M. Cunniff, 1990, "PROBABILISTIC FAILURE ANALYSIS OF SPACE PROPULSION SYSTEM MAIN COMBUSTION CHAMBER LINER," Rocketdyne, Rockwell International, unpublished
- 5.4) Rajagopal, K. R., G. Orient, J. F. Newell and M. McGaw, November 13-14, 1991, "AN ADVANCED METHOD FOR TRACKING THE EVOLUTION OF FATIGUE DAMAGE IN REUSABLE SPACE PROPULSION SYSTEM," Third Annual Health Monitoring Conference for Space Propulsion System, Cincinnati, Ohio
- 5.5) Rajagopal, K. R., J. Keremes, H. Ho and G. Orient, April 1992, "A PROBABILISTIC APPROACH TO THE EVALUATION OF FATIGUE DAMAGE IN A SPACE PROPULSION SYSTEM INJECTOR ELEMENT," AIAA 33rd Structures, Structural Dynamics and Materials Conference, Dallas, Texas
- 5.6) Orient, G., H. Ho, K. R. Rajagopal, and M. McGaw, November 17-18, 1992, "DEVELOPMENT OF LIFE PREDICTION CAPABILITIES FOR SSME MCC LINER," Fourth Annual Space System Health Management Technology Conference for Space Propulsion System, Cincinnati, Ohio
- 5.7) Newell, J. F., Ho, H. and Kurth, R. E., "The Composite Load Spectra Project", NASA Fifth Conference on Artificial Intelligence for Space Applications, Huntsville, Alabama, May 22-23, 1990

## **APPENDIX A.1**

### **RBSCLM USER INTERFACE FILE USER'S GUIDE**

The RBSCIM user interface file contains load information that is needed to carry out a component life evaluation/prediction. The file is generated at the end of each RBSCIM consultation session. It can be passed to the life evaluation program as an input file without any changes. The file format and variable description are presented below. It is an ASCII text file. Each line is limited to 80 characters long.

Line 1, FORMAT(I6,43X,A31)

NUMREC, TITLE

NUMREC : Number of header lines (or records) including this  
line (or record)

TITLE : Mission ID

Line 2.1 - line 2. (NUMREC),

FORMAT(I6,43X,A31) or FORMAT(A10,39X,A31)

{ IANSQ or ANSQ }, BOTEXT

IANSQ : Integer attribute answer for the component query

ANSQ : Character attribute answer

BOTEXT : Text to explain the attribute

Line 2 is repeated NUMREC times

Line 3, FORMAT(2I6)

NSLICE, NUMLD

NSLICE : Number of time-slices to be analyzed for the mission

NUMLD : Total number of loads including the component load,  
the component local loads, the system dependent loads  
(performance variables and operating loads) and the  
independent loads or primitive variables

Line 4, FORMAT(F6.3,F6.1,F6.1)

PL, STIME, DURPL

PL : Power level of the time slice in decimal unit  
e.g. PL = 1.0 for 100% power

STIME : Starting time of the time slice in second

DURPL : Duration of the time slice in seconds

Line 5.1 - line 5. (NUMLD), FORMAT(2I6,1X,A10,2(1X,1PE12.5),A31)

LDTYPE, LOADID, LDNAME, P1, P2, BOTEXT

LDTYPE : Load type or component ID

= -1 For primitive variable (or independent load)

= 0 For system dependent load

= N Integer designates a component ID

LOADID : Load ID number

LDNAME : Load name

P1 : Mean value of the load

P2 : Normalized variation of the load

It is the estimated standard deviation if the load is  
the component load or component local load

BOTEXT : Load description in 30 characters

Line 5 is repeated NUMLD times

The block of lines 4 and 5 is repeated NSLICE times. Each block presents load data for its respected time-slice.

Repeat lines 3, 4, and 5 and associated time-slice blocks for other missions as many times as there are missions to be analyzed.

```
Line 6, FORMAT(2I6)
DUMMY1, DUMMY2
    DUMMY1 = 0
    DUMMY2 = 0
```

Line 6 is the last line of the file signalling the end of the load information

A sample user interface file generated by the RBSCLM run recorded in Appendix A.2 is presented in the next two pages.

# RBSCLM USER INTERFACE FILE

7				MISSION-ID SAS61A	
6				LOX Post	
THREAD				LOX Post Thread Location	
45				Low Cycle Fatigue Damage	
6				LOX Post	
THREAD				LOX Post Thread Location	
46				High Cycle Fatigue Damage	
2	31				
1.000	0.0	100.0*****			
6	45	LPTHRLCF	1.00000E+00	5.00000E-02	
6	48	FLHGFSLP	1.48917E+02	0.00000E+00	Hot gas Flowrate f-side, LO
6	29	TMHGFSLP	1.64490E+03	0.00000E+00	Hot gas Temp. f-side, LOX P
6	72	RMHGIJLP	8.50635E-01	0.00000E+00	Hot gas MR, Injector
6	20	TMLOTHLP	2.11621E+02	0.00000E+00	LOX Temp. at LOX Post threa
6	550	FLHGTLLP	2.12445E+02	0.00000E+00	Total hot gas Flowrate, LOX
6	17	PRLOTHLP	3.05006E+03	0.00000E+00	LOX Pres. at LOX Post threa
6	91	FLLOMILP	7.93440E+02	0.00000E+00	LOX flowrate, Main Injector
6	46	LPTHRHCF	1.00000E+00	5.00000E-02	
6	531	HG-GF	1.00000E+00	5.00000E-02	Hot Gas G factor, heat tran
6	530	COOL-GF	1.00000E+00	5.00000E-02	Coolant G factor, heat tran
6	536	HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
6	535	HG-DENS	6.20967E-01	1.00000E-02	Hot Gas Density
0	48	HPFT-FL	1.58920E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
0	29	HFTTD-TO	1.62572E+03	0.00000E+00	HPFT T/D DISCHARGE TEMPERAT
0	72	HPFT-MR	9.26660E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
0	20	HPOP-TO	1.90195E+02	0.00000E+00	HPOP DISCHARGE TEMPERATURE
0	47	HPOT-FL	5.89473E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
0	17	MCC-IEP	3.00600E+03	0.00000E+00	MCC INJECTOR END PRESSURE
0	91	HPOP-VO	1.74213E+02	0.00000E+00	HPOP DISCHARGE VELOCITY (FT
0	16	MCCHG-IP	3.23736E+03	0.00000E+00	MCC HOT GAS INJECTOR PRESSU
-1	58	HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
-1	19	HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
-1	17	HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
-1	5	O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET TEMPERATURE
-1	21	HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
-1	59	HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
-1	64	ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER ERROR

-1	63	MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR (%)
-1	12	MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
-1	33	MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR RESIST
1.040	100.0	400.0*****			
6	45	LPTHRLCF	1.00000E+00	5.00000E-02	
6	48	FLHGFSLP	1.57345E+02	0.00000E+00	Hot gas Flowrate f-side, LO
6	29	TMHGFSLP	1.67390E+03	0.00000E+00	Hot gas Temp. f-side, LOX P
6	72	RMHGIJLP	8.71582E-01	0.00000E+00	Hot gas MR, Injector
6	20	TMLOTHLP	2.13840E+02	0.00000E+00	LOX Temp. at LOX Post threa
6	550	FLHGTLPL	2.23940E+02	0.00000E+00	Total hot gas Flowrate, LOX
6	17	PRLOTHLP	3.17077E+03	0.00000E+00	LOX Pres. at LOX Post threa
6	91	FLLOMILP	8.23587E+02	0.00000E+00	LOX flowrate, Main Injector
6	46	LPTHRRCF	1.00000E+00	5.00000E-02	
6	531	HG-GF	1.00000E+00	5.00000E-02	Hot Gas G factor, heat tran
6	530	COOL-GF	1.00000E+00	5.00000E-02	Coolant G factor, heat tran
6	536	HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
6	535	HG-DENS	6.35883E-01	1.00000E-02	Hot Gas Density
0	48	HPFT-FL	1.67246E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
0	29	HFTTD-TO	1.65472E+03	0.00000E+00	HPFT T/D DISCHARGE TEMPERAT
0	72	HPFT-MR	9.48013E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
0	20	HPOP-TO	1.91648E+02	0.00000E+00	HPOP DISCHARGE TEMPERATURE
0	47	HPOT-FL	6.18861E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
0	17	MCC-IEP	3.12624E+03	0.00000E+00	MCC INJECTOR END PRESSURE
0	91	HPOP-VO	1.80853E+02	0.00000E+00	HPOP DISCHARGE VELOCITY (FT
0	16	MCCHG-IP	3.37357E+03	0.00000E+00	MCC HOT GAS INJECTOR PRESSU
-1	58	HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
-1	19	HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
-1	17	HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
-1	5	O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET TEMPERATURE
-1	21	HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
-1	59	HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
-1	64	ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER ERROR
-1	63	MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR (%)
-1	12	MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
-1	33	MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR RESIST
0	0				

## APPENDIX A.2

A UNIX log file for a RBSCLM run

```
## Script started on Wed May 22 13:52:38 1991
##
## Lines begin with '##' are comments added to the log-file after
## the run
##
## To run the Composite Load Spectra Load Expert System,
## enter ldrbms40 at the command line
##
```

```
snowman% ldrbms40
```

```
##
## LDEXPT message
##
```

```
*****
```

```
WELCOME TO THE COMPOSITE LOAD SPECTRA EXPERT SYSTEM
```

```
LDEXPT V4.0
```

```
*****
```

```
##
## This is the first prompt from LDEXPT
##
```

```
Is this a debug run ?
```

```
?
```

```
##
## User's response
## Y : Yes, it is a debug run. Every I/O's to the knowledge
## base will be echoed to the screen
## N : No, not a debug run.
##
```

```
N
```

```
##
```

```
## LDEXPT prompt
##
```

Do you wish to open a user interface file ?  
e.g. an interface file for Damage Calculation Module  
(Y/N) ?

```
##
## User's response
## Y : Yes, open a user interface file
## N : No, do not open a user file
##
```

Y

```
##
## LDEXPT prompt
## This prompt will be skipped if the last user's response is N
##
```

Please enter a file-name  
?

```
##
## User's response
## Enter a file name
##
```

LDSCLM40

##  
## LDEXPT prompt  
##

Please choose DATABASE display options:

- (0) Prompt user for display option
- (1) Display full record-by-record
- (2) Display full records by lines
- (3) Display field values only
- (4) Display key values only
- (5) No display

?

##  
## User's response  
## 0 : Prompt for display option every time a database record  
## is retrieved  
## 1 : Option for displaying every record one at a time  
## 2 : Option for displaying all retrieved records by line  
## format  
## 3 : Option for displaying certain field values  
## 4 : Option for displaying certain key values  
## 5 : Option for not displaying any database records  
##

5

```

##
## LDEXPT prompt
## ?EXDR is a subcommand within RBMS
## go to the expert system driver
## ?DBMS is a subcommand within KBMS
## go to the database management system
##

```

Available COMMANDS:

```

?RBMS Rules-Base Management System
?EXDR
?KBMS Knowledge-Base Management System
?DBMS
?HELP List available COMMANDS
?QUIT Exit LDEXPT

```

```

LDEXPT ==>
LDEXPT ==> COMPOSITE LOAD SPECTRA EXPERT SYSTEM
LDEXPT ==>
?

```

```

##
## User's response
##

```

?EXDR

```

##
## LDEXPT is in the expert system driver (or control) module
##
## LDEXPT expert system driver's menu
##
## List of available rule modules
## For the SUN network version, not all rule modules listed
## here are operational
##

```

Available rule modules are :

SLIDPL : Independent load information  
SLDEPL : Dependent load information  
SLICGN : Influence coefficients and Gain values  
SLTBCL : Turbine blade component pressure load information  
SLTHCL : Component load information other than turbine blade  
SLSCTH : Component thermal load influence model information  
SLICTH : Component thermal load influence gains  
SLCLFP : Component fluctuation pressure load information  
SLDUCT : Duct geometry information for fluctuation pressure loads  
SLDDYN : Select DUCT dynamic load PSD information  
SLDCD : Duty-Cycle-Data file information  
QLM : Quick Look Model calculation  
SICM : Deterministic Influence Coefficient Model  
SCLM : Structural Component Life Model  
STBSM : Simple Turbine Blade Scaling Model  
FPSM : Duct Fluctuation Pressure Scaling Model  
TBPRLI : Turbine Blade Linear Interpolation Pressure Data  
ANLDIN : Preparing ANLOAD INput file  
EXIT : Return to RBMS

##  
## User's response  
## Select the structural component life model module  
##

SCLM

##  
## LDEXPT prompt for opening a KNOWLEDGE BASE file  
## At this time, only one KB file loadlm is available  
##

```
*      *      *      *      *      *      *
*      OPEN A DATABASE FILE &/or      *
*      READ A DB TABLE DICTIONARY    *
*      *      *      *      *      *      *
```

Please Enter DB File NAME

# AVAILABLE DB FILES

loadlm : A DIRECT FILE FOR LARGE IC SET

?

##

## User's response

## Enter KB file name loadlm

##

loadlm

##

## LDEXPT message indicates that loadlm is open

## and it is a direct file

## The full path name of the KB file listed

## The database table names (group names) of KB given

## The title database records printed. It is empty for loadlm

##

Open a direct file from OPNOFL \*\*\*\*

ANAME = /home/snowman2/r402433/com1s2/ldexpt40/loadlm

	GRP NAME	GRP #	# OF REC. LAST GRP
DBNREF TABLE	TITL	1	1
DBNREF TABLE	LIDP	1	45
DBNREF TABLE	LDEP	1	45
DBNREF TABLE	INFC	99	45
DBNREF TABLE	SCLM	1	45
DBNREF TABLE	LCTH	1	45
TITL***			
TITL***			
TITL***			

```
##
## LDEXPT message indicating that it was working
## to retrieve databases
##
```

```
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
```

```
##
## LDEXPT message
##
```

```
*****
*
* WELCOME to RBSCLM *
* The CLS STRUCTURAL COMPONENT LIFE MODEL *
* RULE MODULE *
*
*****
```

```
##
```

## RBSCLM prompt for flight or test mission ID  
##

Please Enter FLIGHT- or TEST-ID  
for this mission life evaluation  
?

##  
## User's response  
## For example, flight mission STS61A  
##

STS61A

##  
## RBSCLM prompt for the number of time slices  
##

How many time slices in this mission  
do you want to evaluate ?  
?

##  
## User's response  
##

2

##  
## RBSCLM expert system query for component ID  
## At this time, only 6 is available  
##

Please select a component ID  
1 HPFT (NA)  
5 HGM Fuel Center Transfer Tube (NA)  
6 LOX Post  
7 LOX Post region B (NA)  
8 LOX Post region C (NA)  
9 HGM Oxidizer Transfer Duct (NA)  
10 HPOP Discharge Duct (NA)  
11 LOX Posts Oxidizer Side (NA)  
12 Main Combustion Chamber (NA)

##  
## User's response selecting LOX post  
##

6

```
##
## RBSCLM expert system query for component location
##
```

```
Which is the location of the COMPONENT that you want to analyze ?
Please enter the key word: THREAD, IN-WELD
THREAD : Thread location
IN-WELD: Inertia Weld location
```

```
##
## User's response
## For example, selecting the threaded region
##
```

THREAD

```
##
## RBSCLM expert system query for failure mode
##
```

```
What is the FAILURE MODE that you want to consider ?
45 LCF (Low Cycle Fatigue) Damage
46 HCF (High Cycle Fatigue) Damage
```

```
##
## User's response
## For example, selecting the low cycle fatigue failure
##
```

45

```
##
## RBSCLM expert system query for more loads
##
```

\*\*\* STRUCTURAL COMPONENT LOADS \*\*\*

```
Would you like to request more load ?
Y = Yes; N = No
```

##  
##  
##

User's response

Y

##  
##  
##

RBSCLM expert system query for more component load

Please select a component ID

- 1 HPFT (NA)
- 5 HGM Fuel Center Transfer Tube (NA)
- 6 LOX Post
- 7 LOX Post region B (NA)
- 8 LOX Post region C (NA)
- 9 HGM Oxidizer Transfer Duct (NA)
- 10 HPOP Discharge Duct (NA)
- 11 LOX Posts Oxidizer Side (NA)
- 12 Main Combustion Chamber (NA)

6

Which is the location of the COMPONENT that you want to analyze ?

Please enter the key word: THREAD, IN-WELD

THREAD : Thread location

IN-WELD: Inertia Weld location

THREAD

What is the FAILURE MODE that you want to consider ?

- 45 LCF (Low Cycle Fatigue) Damage
- 46 HCF (High Cycle Fatigue) Damage

46

\*\*\* STRUCTURAL COMPONENT LOADS \*\*\*

Would you like to request more load ?

Y = Yes; N = No

N

##  
##  
##

LDEXPT message indicating it is retrieving databases

\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
\*\*\*\*\*  
\*\*\*\*\* Retrieving DATABASE  
\*\*\*\*\*  
\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
\*\*\*\*\*  
\*\*\*\*\* Retrieving DATABASE  
\*\*\*\*\*  
\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
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\*\*\*\*\* Retrieving DATABASE  
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\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
\*\*\*\*\*  
\*\*\*\*\* Retrieving DATABASE  
\*\*\*\*\*  
\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
\*\*\*\*\*  
\*\*\*\*\* Retrieving DATABASE  
\*\*\*\*\*

```
##
## RBSCLM expert system query for more component local loads
##
```

\*\*\* COMPONENT LOCAL LOADS \*\*\*

Would you like to request more load ?  
Y = Yes; N = No

N

```
##
## LDEXPT message indicating it is entering the RBSICM module
## i.e. the engine system model evaluation module
## The module is retrieving automatically the system dependent
## loads from the database
##
```

```
***** DETERMINISTIC INFLUENCE COEFF. MODEL *****
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
***** FROM GETHDG *****
*****
***** Retrieving DATABASE
*****
```

```
##
## RBSICM expert system query for independent load select
## option
##
```

Select Options for INDEPENDENT LOADS

MANUAL : User selects the independent loads  
ESASIS : Expert System selects the indep. loads  
          based on info in BBOARD (working memory)

##  
## User's response selecting the ESASIS (expert system assist)  
## option  
##

ESASIS

##  
## RBSICM prompt for the number of the most influential  
## independent loads or primitive variables to be selected  
## for each system dependent loads  
##

      \*      \*      \*      \*      \*      \*      \*  
The EXPERT SYSTEM will select the independent  
loads based on the GAIN 's in database INFC  
      \*      \*      \*      \*      \*      \*      \*

How many independent loads need to be selected  
for each dependent load by the expert system ?

##  
## User's response  
##

2

##  
## RBSICM prompt for power level at which the selection  
## of the independent loads or primitive variables was  
## performed  
##

Selection based on which power level

- (1) 65% POWER LEVEL
- (2) 90% POWER LEVEL
- (3) 100% POWER LEVEL
- (4) 104% POWER LEVEL

?

##

## User's response

## Selection was done at 100% power level

##

3

##

## LDEXPT message

##

\*\*\*\*\* FROM GETHDG \*\*\*\*\*

\*\*\*\*\*

\*\*\*\*\* Retrieving DATABASE

\*\*\*\*\*

\*\*\*\*\* FROM GETHDG \*\*\*\*\*

\*\*\*\*\*

\*\*\*\*\* Retrieving DATABASE

\*\*\*\*\*

\*\*\*\*\* FROM GETHDG \*\*\*\*\*

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\*\*\*\*\* Retrieving DATABASE

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\*\*\*\*\* FROM GETHDG \*\*\*\*\*

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\*\*\*\*\* Retrieving DATABASE

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\*\*\*\*\* FROM GETHDG \*\*\*\*\*

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\*\*\*\*\* Retrieving DATABASE  
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\*\*\*\*\* FROM GETHDG \*\*\*\*\*  
\*\*\*\*\*

[illegible]

◆◆

```
## RBSICM prompt for power level of the time slice where
## loads are to be evaluated
##
```

```
Please enter PowerLevel,Start-TimeSlice,Duration
?
```

```
##
## User's input
##
```

```
1.0,0.0,100
```

```
##
## RBSICM prompt for method of calculating the independent
## loads or primitive variables
##
```

```
Method of Calculating Independent Loads
```

```
Please choose input format :
```

- (1) Input Percentage changes of the indep. loads
- (2) Input Point values for the indep. loads

```
##
## User's response selecting option 1
##
```

```
1
```

```
##
## RBSICM prompt
##
```

Please enter values of the following indep. loads:

HPFT-FLC

:

?

##

## User input : 0% change

## i.e. using the mean values for the independent loads

##

0

##

## RBSICM prompt

##

HPFT-EM

:

?

##

## User input

##

0

##

## RBSICM prompt

##

HPFP-EM

:

?

##

## User input

##

0

##  
## RBSICM prompt  
##

O-TI :  
?

##  
## User input  
##

0

##  
## RBSICM prompt  
##

HPOP-EM :  
?

##  
## User input  
##

0

##  
## RBSICM prompt  
##

HPOT-FLC :  
?

##  
## User input  
##

0

##  
## RBSICM prompt  
##

ENG-FFLE :  
?

##  
## User input  
##

0

##  
## RBSICM prompt  
##

MCC-PCER :  
?

##  
## User input  
##

0

##  
## RBSICM prompt  
##

MCC-TH-D :  
?

##  
## User input  
##

0

```
##
##  RBSICM prompt
##
```

```
MCC-HGIR      :
?
```

```
##
##  User input
##
```

0

```
##
##  RBSCLM user interface file output as shown on screen
##
```

MISSION-ID	:	7			MISSION-ID SAS61A
	:	6			LOX Post
	:	THREAD			LOX Post Thread Location
	:	45			Low Cycle Fatigue Damage
	:	6			LOX Post
	:	THREAD			LOX Post Thread Location
	:	46			High Cycle Fatigue Damage
	:	2	31		
POWER LEVEL	:	1.000	0.0	100.0*****	
CMPN-ID	:	6	45	LPTHRLCF	1.00000E+00 5.00000E-02
CMPN-ID	:	6	48	FLHGFSLP	1.48917E+02 0.00000E+00
CMPN-ID	:	6	29	TMHGFSLP	1.64490E+03 0.00000E+00
CMPN-ID	:	6	72	RMHGIJLP	8.50635E-01 0.00000E+00
CMPN-ID	:	6	20	TMLOTHLP	2.11621E+02 0.00000E+00
CMPN-ID	:	6	550	FLHGTLLP	2.12445E+02 0.00000E+00
CMPN-ID	:	6	17	PRLOTHLP	3.05006E+03 0.00000E+00
CMPN-ID	:	6	91	FLLOMILP	7.93440E+02 0.00000E+00
CMPN-ID	:	6	46	LPTHRLHCF	1.00000E+00 5.00000E-02
CMPN-ID	:	6	531	HG-GF	1.00000E+00 5.00000E-02
CMPN-ID	:	6	530	COOL-GF	1.00000E+00 5.00000E-02

Hot gas Flowrate f-side, LO  
Hot gas Temp. f-side, LOX P  
Hot gas MR, Injector  
LOX Temp. at LOX Post threa  
Total hot gas Flowrate, LOX  
LOX Pres. at LOX Post threa  
LOX flowrate, Main Injector  
  
Hot Gas G factor, heat tran  
Coolant G factor, heat tran

Hit any key to continue

CMPN-ID	:	6	536 HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
CMPN-ID	:	6	535 HG-DENS	6.20967E-01	1.00000E-02	Hot Gas Density
LDEP-ID	:	0	48 HPFT-FL	1.58920E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
LDEP-ID	:	0	29 HFTTD-TO	1.62572E+03	0.00000E+00	HPFT T/D DISCHARGE TEMPERAT
LDEP-ID	:	0	72 HPFT-MR	9.26660E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
LDEP-ID	:	0	20 HPOP-TO	1.90195E+02	0.00000E+00	HPOP DISCHARGE TEMPERATURE
LDEP-ID	:	0	47 HPOT-FL	5.89473E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
LDEP-ID	:	0	17 MCC-IEP	3.00600E+03	0.00000E+00	MCC INJECTOR END PRESSURE
LDEP-ID	:	0	91 HPOP-VO	1.74213E+02	0.00000E+00	HPOP DISCHARGE VELOCITY (FT
LDEP-ID	:	0	16 MCCHG-IP	3.23736E+03	0.00000E+00	MCC HOT GAS INJECTOR PRESSU
LIDP-ID	:	-1	58 HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
LIDP-ID	:	-1	19 HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
LIDP-ID	:	-1	17 HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
LIDP-ID	:	-1	5 O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET TEMPERATURE
LIDP-ID	:	-1	21 HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
LIDP-ID	:	-1	59 HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
LIDP-ID	:	-1	64 ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER ERROR
LIDP-ID	:	-1	63 MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR (%)
LIDP-ID	:	-1	12 MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
LIDP-ID	:	-1	33 MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR RESIST

Hit any key to continue

##  
## RBSCLM message  
##

\* \* \* \* \*  
This run is for mission time-slice No. 2  
\* \* \* \* \*

Please enter PowerLevel, Start-TimeSlice, Duration  
?  
1.04,100,400

Methods of Calculating the Independent Loads  
Please choose an input format :

- (1) Input Percentage changes in the indep. loads
- (2) Input Point values for the indep. loads

1  
Please enter values of the following indep. loads:

HPFT-FLC :  
?

0  
HPFT-EM :  
?

0  
HPFP-EM :  
?

0  
O-TI :  
?

0  
HPOP-EM :  
?

0  
HPOT-FLC :  
?

0  
ENG-FFLE :  
?

0  
MCC-PCER :

?  
0  
MCC-TH-D :  
?  
0  
MCC-HGIR :  
?  
0

MISSION-ID	:	7				MISSION-ID SAS61A
	:	6				LOX Post
	:	THREAD				LOX Post Thread Location
	:	45				Low Cycle Fatigue Damage
	:	6				LOX Post
	:	THREAD				LOX Post Thread Location
	:	46				High Cycle Fatigue Damage
	:	2	31			
POWER LEVEL	:	1.000	0.0	100.0*****		
CMPN-ID	:	6	45	LPTHRLCF	1.00000E+00	5.00000E-02
CMPN-ID	:	6	48	FLHGFSLP	1.48917E+02	0.00000E+00
CMPN-ID	:	6	29	TMHGFSLP	1.64490E+03	0.00000E+00
CMPN-ID	:	6	72	RMHGIJLP	8.50635E-01	0.00000E+00
CMPN-ID	:	6	20	TMLOTHLP	2.11621E+02	0.00000E+00
CMPN-ID	:	6	550	FLHGTLPL	2.12445E+02	0.00000E+00
CMPN-ID	:	6	17	PRLOTHLP	3.05006E+03	0.00000E+00
CMPN-ID	:	6	91	FLLMILP	7.93440E+02	0.00000E+00
CMPN-ID	:	6	46	LPTHRHCF	1.00000E+00	5.00000E-02
CMPN-ID	:	6	531	HG-GF	1.00000E+00	5.00000E-02
CMPN-ID	:	6	530	COOL-GF	1.00000E+00	5.00000E-02

Hot gas Flowrate f-side, LO  
Hot gas Temp. f-side, LOX P  
Hot gas MR, Injector  
LOX Temp. at LOX Post threa  
Total hot gas Flowrate, LOX  
LOX Pres. at LOX Post threa  
LOX flowrate, Main Injector  
Hot Gas G factor, heat tran  
Coolant G factor, heat tran

Hit any key to continue

CMPN-ID	:	6	536	HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
CMPN-ID	:	6	535	HG-DENS	6.20967E-01	1.00000E-02	Hot Gas Density
LDEP-ID	:	0	48	HPFT-FL	1.58920E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
LDEP-ID	:	0	29	HFTTD-TO	1.62572E+03	0.00000E+00	HPFT T/D DISCHARGE TEMPERAT
LDEP-ID	:	0	72	HPFT-MR	9.26660E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
LDEP-ID	:	0	20	HPOP-TO	1.90195E+02	0.00000E+00	HPOP DISCHARGE TEMPERATURE
LDEP-ID	:	0	47	HPOT-FL	5.89473E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
LDEP-ID	:	0	17	MCC-IEP	3.00600E+03	0.00000E+00	MCC INJECTOR END PRESSURE
LDEP-ID	:	0	91	HPOP-VO	1.74213E+02	0.00000E+00	HPOP DISCHARGE VELOCITY (FT
LDEP-ID	:	0	16	MCCHG-IP	3.23736E+03	0.00000E+00	MCC HOT GAS INJECTOR PRESSU
LIDP-ID	:	-1	58	HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
LIDP-ID	:	-1	19	HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
LIDP-ID	:	-1	17	HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
LIDP-ID	:	-1	5	O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET TEMPERATURE
LIDP-ID	:	-1	21	HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
LIDP-ID	:	-1	59	HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
LIDP-ID	:	-1	64	ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER ERROR
LIDP-ID	:	-1	63	MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR (%)
LIDP-ID	:	-1	12	MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
LIDP-ID	:	-1	33	MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR RESIST

Hit any key to continue

POWER LEVEL	:	1.040	100.0	400.0*****			
CMPN-ID	:	6	45	LPTHRLCF	1.00000E+00	5.00000E-02	
CMPN-ID	:	6	48	FLHGFSLP	1.57345E+02	0.00000E+00	Hot gas Flowrate f-side, LO
CMPN-ID	:	6	29	TMHGFSLP	1.67390E+03	0.00000E+00	Hot gas Temp. f-side, LOX P
CMPN-ID	:	6	72	RMHGIJLP	8.71582E-01	0.00000E+00	Hot gas MR, Injector
CMPN-ID	:	6	20	TMLOTHLP	2.13840E+02	0.00000E+00	LOX Temp. at LOX Post threa
CMPN-ID	:	6	550	FLHGTLPL	2.23940E+02	0.00000E+00	Total hot gas Flowrate, LOX
CMPN-ID	:	6	17	PRLOTHLP	3.17077E+03	0.00000E+00	LOX Pres. at LOX Post threa
CMPN-ID	:	6	91	FLLOMILP	8.23587E+02	0.00000E+00	LOX flowrate, Main Injector
CMPN-ID	:	6	46	LPTHRHCF	1.00000E+00	5.00000E-02	
CMPN-ID	:	6	531	HG-GF	1.00000E+00	5.00000E-02	Hot Gas G factor, heat tran
CMPN-ID	:	6	530	COOL-GF	1.00000E+00	5.00000E-02	Coolant G factor, heat tran

CMPN-ID	:	6	536 HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
CMPN-ID	:	6	535 HG-DENS	6.35883E-01	1.00000E-02	Hot Gas Density
LDEP-ID	:	0	48 HPFT-FL	1.67246E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
LDEP-ID	:	0	29 HFTTD-TO	1.65472E+03	0.00000E+00	HPFT T/D DISCHARGE TEMPERAT
LDEP-ID	:	0	72 HPFT-MR	9.48013E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
LDEP-ID	:	0	20 HPOP-TO	1.91648E+02	0.00000E+00	HPOP DISCHARGE TEMPERATURE
LDEP-ID	:	0	47 HPOT-FL	6.18861E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
LDEP-ID	:	0	17 MCC-IEP	3.12624E+03	0.00000E+00	MCC INJECTOR END PRESSURE

Hit any key to continue

LDEP-ID	:	0	91 HPOP-VO	1.80853E+02	0.00000E+00	HPOP DISCHARGE VELOCITY (FT
LDEP-ID	:	0	16 MCCHG-IP	3.37357E+03	0.00000E+00	MCC HOT GAS INJECTOR PRESSU
LIDP-ID	:	-1	58 HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
LIDP-ID	:	-1	19 HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
LIDP-ID	:	-1	17 HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
LIDP-ID	:	-1	5 O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET TEMPERATURE
LIDP-ID	:	-1	21 HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
LIDP-ID	:	-1	59 HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
LIDP-ID	:	-1	64 ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER ERROR
LIDP-ID	:	-1	63 MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR (%)
LIDP-ID	:	-1	12 MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
LIDP-ID	:	-1	33 MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR RESIST

Hit any key to continue

```
##  
##  
##  RBSCLM prompt  
##
```

\*\*\*\*\*

Would you like to obtain loads  
for another MISSION ?  
(Y/N) ?

```
##  
##  User's response  
##    Y : Yes, go back to the beginning of this module and  
##        run load simulation for another mission  
##    N : No, it is time to quit  
##
```

N

##  
##  
##

LDEXPT expert system driver's menu

Available rule modules are :

SLIDPL : Independent load information  
SLDEPL : Dependent load information  
SLICGN : Influence coefficients and Gain values  
SLTBCL : Turbine blade component pressure load information  
SLTHCL : Component load information other than turbine blade  
SLSCTH : Component thermal load influence model information  
SLICTH : Component thermal load influence gains  
SLCLFP : Component fluctuation pressure load information  
SLDUCT : Duct geometry information for fluctuation pressure loads  
SLDDYN : Select DUCT dynamic load PSD information  
SLDCD : Duty-Cycle-Data file information  
QLM : Quick Look Model calculation  
SICM : Deterministic Influence Coefficient Model  
SCLM : Structural Component Life Model  
STBSM : Simple Turbine Blade Scaling Model  
FPSM : Duct Fluctuation Pressure Scaling Model  
TBPRLI : Turbine Blade Linear Interpolation Pressure Data  
ANLDIN : Preparing ANLOAD Input file  
EXIT : Return to RBMS

##  
##  
##

User's response

EXIT

##  
## LDEXPT prompt for saving the expert system log-file  
## The log-file shows the actions taken by the expert system  
## during the process. It could help users to understand the  
## process.  
##

DO YOU WANT TO SAVE THE LOGFILE (Y/N) ?

##  
## User's response  
##

Y

##  
## LDEXPT exits the expert system driver and  
## returns to the LDEXPT control module (top level)  
## At this point, users can find out possible commands at this  
## level by enter ?HELP  
##

C-2  
LDEXPT ==>  
LDEXPT ==> COMPOSITE LOAD SPECTRA EXPERT SYSTEM  
LDEXPT ==>  
?

##  
## User's response for ending and leaving the program  
##

?QUIT

## APPENDIX A.3

A LDEXPT Expert System log file for a RBSCLM run

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute TOPICS

\*\*\*\*\*

SCLM            Providing Structural Comp. Life Model Info and Databases

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute CMPN-ID

\*\*\*\*\*

6               LOX Post

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LOXPLOC

\*\*\*\*\*

THREAD         LOX Post Thread Location

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LOXPFM

\*\*\*\*\*

45              Low Cycle Fatigue Damage

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute MORE

\*\*\*\*\*

Y               Yes, more load please

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute CMPN-ID

\*\*\*\*\*

6               LOX Post

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LOXPLOC

\*\*\*\*\*

THREAD         LOX Post Thread Location

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LOXPFM

\*\*\*\*\*

46              High Cycle Fatigue Damage

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute MORE

\*\*\*\*\*

N               No, no more loads

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE SCLM  
\*\*\*\*\* the following records :

\*\*\*\*\*

CMPN-ID	CMPN-LOC	C-LD-ID	C-LD-NA	LD-TYPE	LDEP1-ID
LDEP2-ID	LDEP3-ID	LDEP4-ID	LDEP5-ID	LDEP6-ID	LDEP7-ID
LDEP8-ID	LDEP9-ID	LDEPA-ID			
6	THREAD	45	LPTHRLCF	TEN	6048
6029	6072	6020	6047	6017	6091
6531	6530	6536			
6	THREAD	46	LPTHRHCF	FOUR	6048
16	29	6535	0	0	0
0	0	0			

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE LCTH  
\*\*\*\*\* the following records :

\*\*\*\*\*

CMPN-ID	C-LD-ID	C-LD-NA	MEAN	COV	P3
DIST	NE-COEF1	NE-COEF2	NE-COEF3	NE-COEF4	
6	531	HG-GF	0.10000E+01	0.50000E-01	0.00000E+00
NORMAL	0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00	
6	530	COOL-GF	0.10000E+01	0.50000E-01	0.00000E+00
NORMAL	0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00	
6	536	HAY-KF	0.10000E+01	0.10000E+00	0.00000E+00
NORMAL	0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00	
6	535	HG-DENS	0.68000E+00	0.10000E-01	0.00000E+00
NORMAL	0.68000E-01	0.00000E+00	0.00000E+00	0.00000E+00	

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute C-LD-ID

\*\*\*\*\*

531 Hot Gas G factor, heat transfer film coefficient

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute C-LD-ID

\*\*\*\*\*

530 Coolant G factor, heat transfer film coefficient

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute C-LD-ID

\*\*\*\*\*

536 Haynes 188 K factor

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute C-LD-ID

\*\*\*\*\*

535 Hot Gas Density

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute MORE

\*\*\*\*\*

N No, no more loads

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE LDEP

\*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LD-NAME	MEAN	COV	P3	DIST
NE-COEF1	NE-COEF2	NE-COEF3	NE-COEF4		
48	HPFT-FL	0.15892E+03	0.10700E-01	0.00000E+00	NORMAL
-0.21408E+02	0.18003E+03	-0.25126E+02	0.25427E+02		
29	HFTTD-TO	0.16257E+04	0.19300E-01	0.00000E+00	LOGNOR
0.16508E+04	-0.74634E+03	0.72124E+03	0.00000E+00		
72	HPFT-MR	0.92666E+00	0.22700E-01	0.00000E+00	NORMAL
0.90289E+00	-0.46666E+00	0.49043E+00	0.00000E+00		
20	HPOP-TO	0.19020E+03	0.20000E-02	0.00000E+00	LOGNOR
0.16537E+03	0.12097E+02	0.14330E+02	-0.16062E+01		
47	HPOT-FL	0.58947E+02	0.10100E-01	0.00000E+00	NORMAL
-0.56674E+01	0.64785E+02	-0.85220E+01	0.83520E+01		
17	MCC-IEP	0.30060E+04	0.58000E-02	0.00000E+00	NORMAL
-0.29977E-02	0.30060E+04	-0.44735E-02	0.00000E+00		
91	HPOP-VO	0.17421E+03	0.52000E-02	0.00000E+00	NORMAL
0.73869E+01	0.16763E+03	-0.80185E+00	0.00000E+00		
16	MCCHG-IP	0.32374E+04	0.64000E-02	0.00000E+00	NORMAL
0.36679E+02	0.30039E+04	0.19674E+03	0.00000E+00		

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

48 HPFTP TURBINE FLOWRATE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

29 HPFT T/D DISCHARGE TEMPERATURE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

72 HPFT MIXTURE RATIO (O/F)

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

20 HPOP DISCHARGE TEMPERATURE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

47 HPOTP TURBINE FLOWRATE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

17 MCC INJECTOR END PRESSURE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

91 HPOP DISCHARGE VELOCITY (FT/S)

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LDEP-ID

\*\*\*\*\*

16 MCC HOT GAS INJECTOR PRESSURE

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute SILOPT

\*\*\*\*\*

ESASIS Automatic selection of indep. loads by LDEXPT

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE LIDP

\*\*\*\*\* the following records :

\*\*\*\*\*

LIDP-ID	LD-NAME	MEAN	COV	P3	DIST
NE-COEF1	NE-COEF2	NE-COEF3	NE-COEF4		
58	HPFT-FLC	0.10125E+01	0.10000E-01	0.00000E+00	NORMAL
0.10125E+01	0.00000E+00	0.00000E+00	0.00000E+00		
19	HPFT-EM	0.10355E+01	0.10000E-01	0.00000E+00	NORMAL
0.10355E+01	0.00000E+00	0.00000E+00	0.00000E+00		
17	HPFP-EM	0.10000E+01	0.80000E-02	0.00000E+00	NORMAL
0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00		
5	O-TI	0.16400E+03	0.80000E-02	0.00000E+00	LOGNOR
0.16400E+03	0.00000E+00	0.00000E+00	0.00000E+00		
21	HPOP-EM	0.10200E+01	0.40000E-02	0.00000E+00	NORMAL
0.10200E+01	0.00000E+00	0.00000E+00	0.00000E+00		
59	HPOT-FLC	0.97409E+00	0.10000E-01	0.00000E+00	NORMAL
0.97409E+00	0.00000E+00	0.00000E+00	0.00000E+00		
64	ENG-FFLE	0.10000E+01	0.10000E-03	0.00000E+00	NORMAL
0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00		
63	MCC-PCER	0.10000E+01	0.10000E-03	0.00000E+00	NORMAL
0.10000E+01	0.00000E+00	0.00000E+00	0.00000E+00		
12	MCC-TH-D	0.10293E+02	0.10000E-02	0.00000E+00	NORMAL
0.10293E+02	0.00000E+00	0.00000E+00	0.00000E+00		
33	MCC-HGIR	0.31000E-02	0.25000E-01	0.00000E+00	NORMAL
0.31000E-02	0.00000E+00	0.00000E+00	0.00000E+00		

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

58 HPFT FLOW COEFFICIENT

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

19 HPFT EFFICIENCY (%)

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

17 HPFP EFFICIENCY (%)

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

5 OXIDIZER INLET TEMPERATURE

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

21 HPOP EFFICIENCY (%)

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

59 HPOT FLOW COEFFICIENT

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

64 ENGINE FUEL FLOWMETER ERROR (%)

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

63 MCC PC MEASUREMENT ERROR (%)

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute LIDP-ID  
\*\*\*\*\*

12 MCC THROAT DIAMETER (IN)

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute LIDP-ID

\*\*\*\*\*

33

MCC HOT GAS INJECTOR RESISTANCE

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC

\*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
48	58	0.41872E+00	0.91193E-01	0.00000E+00	0.00000E+00
0.47799E-02	0.50079E-02	0.50991E-02	0.51356E-02		
48	19	-0.25353E+00	0.30745E+00	-0.66112E+00	0.36986E+00
-0.23144E-02	-0.24270E-02	-0.23734E-02	-0.23280E-02		
48	17	-0.39907E-01	-0.48171E+00	0.28987E+00	0.00000E+00
-0.18444E-02	-0.19092E-02	-0.18539E-02	-0.18188E-02		
48	5	0.33745E-01	-0.30826E-01	0.43822E-01	0.00000E+00
0.25779E-03	0.33198E-03	0.37393E-03	0.39267E-03		
48	21	-0.31191E-01	-0.72796E-01	0.00000E+00	0.00000E+00
-0.31403E-03	-0.38683E-03	-0.41595E-03	-0.42759E-03		
48	59	-0.57006E-01	-0.16368E-01	-0.25883E-01	0.00000E+00
-0.78581E-03	-0.92703E-03	-0.99257E-03	-0.10202E-02		
48	64	-0.13442E+01	0.15661E+01	-0.55999E+00	0.00000E+00
-0.56279E-04	-0.38826E-04	-0.33804E-04	-0.32109E-04		
48	63	-0.24159E+00	0.43374E+00	0.00000E+00	0.00000E+00
0.40336E-05	0.14877E-04	0.19214E-04	0.20949E-04		
48	12	0.31982E+00	-0.25727E+00	0.46013E+00	0.00000E+00
0.34700E-03	0.46099E-03	0.52269E-03	0.54994E-03		
48	33	0.39356E-02	0.30436E-01	-0.67915E-02	0.00000E+00
0.52124E-03	0.64567E-03	0.68950E-03	0.70608E-03		

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC

\*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
29	58	0.46027E+00	0.33473E+00	-0.32234E+00	0.00000E+00
0.54166E-02	0.50044E-02	0.47267E-02	0.45975E-02		
29	19	0.13951E+00	-0.26457E+01	0.14600E+01	0.00000E+00
-0.96333E-02	-0.10590E-01	-0.10462E-01	-0.10328E-01		
29	17	0.23760E+00	-0.27898E+01	0.15493E+01	0.00000E+00
-0.73697E-02	-0.81466E-02	-0.80236E-02	-0.79049E-02		
29	5	0.11883E-01	-0.21711E+00	0.80307E-01	0.00000E+00
-0.76248E-03	-0.94775E-03	-0.99938E-03	-0.10164E-02		
29	21	-0.71168E-01	0.68146E+00	-0.33902E+00	0.00000E+00
0.91419E-03	0.10702E-02	0.10851E-02	0.10835E-02		
29	59	-0.18725E-01	0.71086E+00	-0.36147E+00	0.00000E+00
0.29061E-02	0.32826E-02	0.33066E-02	0.32960E-02		
29	64	-0.13992E+01	0.50645E+01	-0.42417E+01	0.00000E+00
0.10063E-04	-0.27689E-04	-0.57635E-04	-0.71989E-04		
29	63	-0.95105E+00	0.40087E+01	-0.32430E+01	0.00000E+00
0.28443E-04	0.29941E-05	-0.18536E-04	-0.28964E-04		

29 12 0.32724E+00-0.26813E+01 0.98459E+00 0.00000E+00  
 0.99960E-03-0.12884E-02-0.13695E-02-0.13964E-02  
 29 33 -0.36231E-01 0.24232E+00-0.12220E+00 0.00000E+00  
 0.17412E-02 0.20720E-02 0.20973E-02 0.20904E-02

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC

\*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
72	58	0.63991E+00	0.15081E+00	-0.27995E+00	0.00000E+00
0.61965E-02	0.54887E-02	0.51076E-02	0.49395E-02		
72	19	-0.13445E+00	-0.25265E+01	0.14238E+01	0.00000E+00
-0.11751E-01	-0.12550E-01	-0.12371E-01	-0.12220E-01		
72	17	-0.57331E-01	-0.26579E+01	0.14888E+01	0.00000E+00
-0.92478E-02	-0.99485E-02	-0.98118E-02	-0.96905E-02		
72	5	-0.70247E-01	-0.10130E+00	0.00000E+00	0.00000E+00
-0.10887E-02	-0.12913E-02	-0.13723E-02	-0.14047E-02		
72	21	-0.36204E-02	0.67738E+00	-0.32359E+00	0.00000E+00
0.11998E-02	0.13757E-02	0.14007E-02	0.14034E-02		
72	59	0.79971E-01	0.67053E+00	-0.33170E+00	0.00000E+00
0.37567E-02	0.41477E-02	0.41880E-02	0.41856E-02		
72	64	-0.26298E+01	0.69166E+01	-0.55861E+01	0.00000E+00
-0.49415E-04	-0.92964E-04	-0.12994E-03	-0.14785E-03		
72	63	-0.16230E+01	0.50717E+01	-0.40598E+01	0.00000E+00
-0.41698E-05	-0.34693E-04	-0.61112E-04	-0.73953E-04		
72	12	-0.53149E+00	-0.12246E+01	0.00000E+00	0.00000E+00
-0.13275E-02	-0.16336E-02	-0.17561E-02	-0.18051E-02		
72	33	-0.24256E-01	0.24773E+00	-0.12480E+00	0.00000E+00
0.21010E-02	0.24403E-02	0.24669E-02	0.24600E-02		

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC

\*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
20	58	0.22661E-03	-0.20895E-02	-0.35531E-02	0.00000E+00
-0.26328E-04	-0.45320E-04	-0.54160E-04	-0.57895E-04		
20	19	-0.42991E-02	0.10716E-01	-0.19310E-02	0.00000E+00
0.18505E-04	0.37813E-04	0.44860E-04	0.47570E-04		
20	17	-0.42010E-02	0.10515E-01	-0.20149E-02	0.00000E+00
0.14259E-04	0.29042E-04	0.34391E-04	0.36441E-04		
20	5	0.98468E+00	0.49574E-01	-0.12556E-01	0.00000E+00
0.80928E-02	0.81530E-02	0.81736E-02	0.81813E-02		
20	21	-0.14771E-01	-0.10498E+00	-0.14307E+00	0.42720E-01
-0.52689E-03	-0.77598E-03	-0.88039E-03	-0.92255E-03		
20	59	0.20178E-02	-0.70305E-02	0.35469E-02	0.00000E+00
-0.10535E-04	-0.14367E-04	-0.14658E-04	-0.14576E-04		
20	64	-0.10487E+00	0.33855E+00	0.12625E+00	0.00000E+00
0.16853E-04	0.30209E-04	0.35993E-04	0.38378E-04		
20	63	-0.81296E-01	0.28790E+00	0.94183E-01	0.00000E+00
0.14563E-04	0.25410E-04	0.30079E-04	0.31999E-04		
20	12	-0.13741E+00	0.30088E+00	0.16044E+00	0.00000E+00
0.12595E-03	0.26334E-03	0.32391E-03	0.34904E-03		

20 33 -0.10367E-02 0.00000E+00 0.00000E+00 0.00000E+00  
 0.25917E-04-0.25917E-04-0.25917E-04-0.25917E-04

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC  
 \*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
47	58	-0.37927E-02	-0.27775E+00	0.12117E+00	0.00000E+00
-0.13313E-02	-0.15562E-02	-0.16037E-02	-0.16159E-02		
47	19	0.16940E+00	-0.88490E+00	0.47399E+00	0.00000E+00
-0.20552E-02	-0.24307E-02	-0.24150E-02	-0.23822E-02		
47	17	0.18927E+00	-0.92763E+00	0.49024E+00	0.00000E+00
-0.16524E-02	-0.19879E-02	-0.19849E-02	-0.19617E-02		
47	5	0.33167E-01	-0.13220E+00	0.88328E-01	0.00000E+00
-0.12358E-03	-0.11418E-03	-0.85682E-04	-0.70327E-04		
47	21	-0.10089E+00	0.20347E+00	-0.14622E+00	0.00000E+00
-0.12164E-03	-0.14480E-03	-0.17454E-03	-0.18971E-03		
47	59	0.36806E+00	0.40878E+00	-0.15445E+00	0.00000E+00
0.56852E-02	0.61086E-02	0.62239E-02	0.62614E-02		
47	64	-0.11393E+01	0.00000E+00	0.00000E+00	0.00000E+00
-0.11393E-03	-0.11393E-03	-0.11393E-03	-0.11393E-03		
47	63	0.69385E-01	-0.11843E+01	0.75084E+00	0.00000E+00
-0.38321E-04	-0.38834E-04	-0.36412E-04	-0.35022E-04		
47	12	0.61165E+00	-0.15934E+01	0.10470E+01	0.00000E+00
0.18285E-04	0.25644E-04	0.65233E-04	0.86932E-04		
47	33	0.73600E-02	0.16058E-01	0.00000E+00	0.00000E+00
0.44495E-03	0.54531E-03	0.58546E-03	0.60151E-03		

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC  
 \*\*\*\*\* the following records :

\*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
17	58	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	19	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	17	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	5	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	21	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	59	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	64	0.99997E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.99997E-04	0.99997E-04	0.99997E-04	0.99997E-04		
17	63	0.99997E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.99997E-04	0.99997E-04	0.99997E-04	0.99997E-04		
17	12	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		
17	33	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00		

\*\*\*\*\*

\*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC  
 \*\*\*\*\* the following records :  
 \*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
91	58	-0.97924E-03	-0.23169E-02	0.00000E+00	0.00000E+00
-0.24852E-04	-0.30645E-04	-0.32962E-04	-0.33888E-04		
91	19	-0.24107E-02	0.97903E-02	-0.47859E-02	0.00000E+00
0.19310E-04	0.25241E-04	0.25938E-04	0.25949E-04		
91	17	-0.22884E-02	0.91138E-02	-0.43449E-02	0.00000E+00
0.14399E-04	0.19157E-04	0.19844E-04	0.19924E-04		
91	5	0.35311E+00	0.38919E-01	-0.18762E-01	0.00000E+00
0.29639E-02	0.29835E-02	0.29862E-02	0.29864E-02		
91	21	0.12438E-01	-0.91151E-01	0.00000E+00	0.00000E+00
-0.18724E-03	-0.27839E-03	-0.31485E-03	-0.32944E-03		
91	59	-0.81423E-03	0.00000E+00	0.00000E+00	0.00000E+00
-0.81423E-05	-0.81423E-05	-0.81423E-05	-0.81423E-05		
91	64	0.18716E+01	0.80498E+00	-0.38901E+00	0.00000E+00
0.22305E-03	0.22810E-03	0.22876E-03	0.22881E-03		
91	63	0.15000E+01	0.64133E+00	-0.31300E+00	0.00000E+00
0.17846E-03	0.18236E-03	0.18283E-03	0.18284E-03		
91	12	0.22605E+01	0.69320E+00	-0.26805E+00	0.00000E+00
0.25979E-02	0.26673E-02	0.26857E-02	0.26915E-02		
91	33	0.16399E-02	-0.57980E-02	0.37249E-02	0.00000E+00
-0.13877E-04	-0.14029E-04	-0.10831E-04	-0.90302E-05		

\*\*\*\*\*  
 \*\*\*\*\* SYSTEM has selected from the DATABASE TABLE INFC  
 \*\*\*\*\* the following records :  
 \*\*\*\*\*

LDEP-ID	LIDP-ID	INFL-C1	INFL-C2	INFL-C3	INFL-C4
GAIN65	GAIN90	GAIN100	GAIN104		
16	58	0.32918E-01	0.11426E-01	0.11331E-01	0.00000E+00
0.45132E-03	0.52379E-03	0.55675E-03	0.57056E-03		
16	19	-0.68359E-02	-0.11668E-01	-0.93566E-01	0.65681E-01
-0.35914E-03	-0.45244E-03	-0.46388E-03	-0.46289E-03		
16	17	-0.26209E-01	0.64916E-01	-0.18710E+00	0.10418E+00
-0.27562E-03	-0.34711E-03	-0.35370E-03	-0.35100E-03		
16	5	0.10119E-01	-0.20205E-01	0.16696E-01	0.00000E+00
0.32315E-04	0.43663E-04	0.52878E-04	0.57311E-04		
16	21	0.23311E-02	-0.42420E-01	0.48291E-01	-0.24925E-01
-0.46735E-04	-0.59604E-04	-0.66889E-04	-0.70363E-04		
16	59	0.27246E-02	0.24572E-01	-0.12736E-01	0.00000E+00
0.13316E-03	0.14524E-03	0.14561E-03	0.14505E-03		
16	64	0.88807E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.88807E-04	0.88807E-04	0.88807E-04	0.88807E-04		
16	63	0.94033E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.94033E-04	0.94033E-04	0.94033E-04	0.94033E-04		
16	12	0.10895E+00	-0.21454E+00	0.18180E+00	0.00000E+00
0.46316E-04	0.63129E-04	0.76217E-04	0.82470E-04		
16	33	0.37985E-01	0.21404E-01	0.11453E-01	0.00000E+00
0.14184E-02	0.16632E-02	0.17711E-02	0.18158E-02		

\*\*\*\*\*  
 \*\*\*\*\* 1.000 0.0 100.0\*\*\*\*\*  
 \*\*\*\*\*

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

FLHGFSLP Hot gas Flowrate f-side, LOX Post

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

TMHGFSLP Hot gas Temp. f-side, LOX Post

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

RMHGIJLP Hot gas MR, Injector

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

TMLOTHLP LOX Temp. at LOX Post threads

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

FLHGTLLP Total hot gas Flowrate, LOX Post

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

PRLOTHLP LOX Pres. at LOX Post threads

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

FLLOMILP LOX flowrate, Main Injector

\*\*\*\*\*  
\*\*\*\*\* Mission time-slice No. 2  
\*\*\*\*\*  
\*\*\*\*\*  
\*\*\*\*\* 1.040 100.0 400.0\*\*\*\*\*  
\*\*\*\*\*

\*\*\*\*\*  
\*\*\*\*\* Expert system QUERY on attribute CL6545  
\*\*\*\*\*

FLHGFSLP Hot gas Flowrate f-side, LOX Post

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

TMHGFSLP Hot gas Temp. f-side, LOX Post

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

RMHGIJLP Hot gas MR, Injector

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

TMLOTHLP LOX Temp. at LOX Post threads

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

FLHGTLPL Total hot gas Flowrate, LOX Post

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

PRLOTHLP LOX Pres. at LOX Post threads

\*\*\*\*\*  
 \*\*\*\*\* Expert system QUERY on attribute CL6545  
 \*\*\*\*\*

FLLOMILP LOX flowrate, Main Injector

\*\*\*\*\*  
 \*\*\*\*\* RBSCLM User Interface File  
 \*\*\*\*\*

7					MISSION-ID SAS61A
6					LOX Post
THREAD					LOX Post Thread Location
45					Low Cycle Fatigue Damage
6					LOX Post
THREAD					LOX Post Thread Location
46					High Cycle Fatigue Damage
2	31				
1.000	0.0	100.0*****			
6	45	LPTHRLCF	1.00000E+00	5.00000E-02	
6	48	FLHGFSLP	1.48917E+02	0.00000E+00	Hot gas Flowrate f-side,
LO					
6	29	TMHGFSLP	1.64490E+03	0.00000E+00	Hot gas Temp. f-side,
OX P					
6	72	RMHGIJLP	8.50635E-01	0.00000E+00	Hot gas MR, Injector

rea	6	20	TMLOTHLP	2.11621E+02	0.00000E+00	LOX Temp. at LOX Post
LOX	6	550	FLHGTLPL	2.12445E+02	0.00000E+00	Total hot gas Flowrate,
threa	6	17	PRLOTHLP	3.05006E+03	0.00000E+00	LOX Pres. at LOX Post
Injector	6	91	FLLMILP	7.93440E+02	0.00000E+00	LOX flowrate, Main
	6	46	LPTHRLCF	1.00000E+00	5.00000E-02	
tran	6	531	HG-GF	1.00000E+00	5.00000E-02	Hot Gas G factor, heat
tran	6	530	COOL-GF	1.00000E+00	5.00000E-02	Coolant G factor, heat
	6	536	HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
	6	535	HG-DENS	6.20967E-01	1.00000E-02	Hot Gas Density
	0	48	HPFT-FL	1.58920E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
	0	29	HFTTD-TO	1.62572E+03	0.00000E+00	HPFT T/D DISCHARGE
TEMPERAT						
	0	72	HPFT-MR	9.26660E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
TURE	0	20	HPOP-TO	1.90195E+02	0.00000E+00	HPOP DISCHARGE TEMPERA-
	0	47	HPOT-FL	5.89473E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
	0	17	MCC-IEP	3.00600E+03	0.00000E+00	MCC INJECTOR END
PRESSURE						
(FT	0	91	HPOP-VO	1.74213E+02	0.00000E+00	HPOP DISCHARGE VELOCITY
RESSU	0	16	MCCHG-IP	3.23736E+03	0.00000E+00	MCC HOT GAS INJECTOR
	-1	58	HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
	-1	19	HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
	-1	17	HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
	-1	5	O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET
TEMPERATURE						
	-1	21	HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
	-1	59	HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
	-1	64	ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER
ERROR						
(%	-1	63	MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR
	-1	12	MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
	-1	33	MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR
RESIST						
	1.040	100.0	400.0*****			
	6	45	LPTHRLCF	1.00000E+00	5.00000E-02	
LO	6	48	FLHGFSPL	1.57345E+02	0.00000E+00	Hot gas Flowrate f-side,
LOX P	6	29	TMHGFSPL	1.67390E+03	0.00000E+00	Hot gas Temp. f-side,
	6	72	RMHGIJLP	8.71582E-01	0.00000E+00	Hot gas MR, Injector
threa	6	20	TMLOTHLP	2.13840E+02	0.00000E+00	LOX Temp. at LOX Post
	6	550	FLHGTLPL	2.23940E+02	0.00000E+00	Total hot gas Flowrate,
OX	6	17	PRLOTHLP	3.17077E+03	0.00000E+00	LOX Pres. at LOX Post
threa						

jector	6	91	FILLOMILP	8.23587E+02	0.00000E+00	LOX flowrate, Main
	6	46	LPTHRHCF	1.00000E+00	5.00000E-02	
	6	531	HG-GF	1.00000E+00	5.00000E-02	Hot Gas G factor, heat
tran	6	530	COOL-GF	1.00000E+00	5.00000E-02	Coolant G factor, heat
tran	6	536	HAY-KF	1.00000E+00	1.00000E-01	Haynes 188 K factor
	6	535	HG-DENS	6.35883E-01	1.00000E-02	Hot Gas Density
	0	48	HPFT-FL	1.67246E+02	0.00000E+00	HPFTP TURBINE FLOWRATE
	0	29	HFTTD-TO	1.65472E+03	0.00000E+00	HPFT T/D DISCHARGE
TEMPERAT						
	0	72	HPFT-MR	9.48013E-01	0.00000E+00	HPFT MIXTURE RATIO (O/F)
	0	20	HPOP-TO	1.91648E+02	0.00000E+00	HPOP DISCHARGE
TEMPERATURE						
	0	47	HPOT-FL	6.18861E+01	0.00000E+00	HPOTP TURBINE FLOWRATE
	0	17	MCC-IEP	3.12624E+03	0.00000E+00	MCC INJECTOR END
PRESSURE						
(FT	0	91	HPOP-VO	1.80853E+02	0.00000E+00	HPOP DISCHARGE VELOCITY
	0	16	MCCHG-IP	3.37357E+03	0.00000E+00	MCC HOT GAS INJECTOR
PRESSU						
	-1	58	HPFT-FLC	1.01250E+00	0.00000E+00	HPFT FLOW COEFFICIENT
	-1	19	HPFT-EM	1.03550E+00	0.00000E+00	HPFT EFFICIENCY (%)
	-1	17	HPFP-EM	1.00000E+00	0.00000E+00	HPFP EFFICIENCY (%)
	-1	5	O-TI	1.64000E+02	0.00000E+00	OXIDIZER INLET
TEMPERATURE						
	-1	21	HPOP-EM	1.02000E+00	0.00000E+00	HPOP EFFICIENCY (%)
	-1	59	HPOT-FLC	9.74086E-01	0.00000E+00	HPOT FLOW COEFFICIENT
	-1	64	ENG-FFLE	1.00000E+00	0.00000E+00	ENGINE FUEL FLOWMETER
ERROR						
(%	-1	63	MCC-PCER	1.00000E+00	0.00000E+00	MCC PC MEASUREMENT ERROR
	-1	12	MCC-TH-D	1.02930E+01	0.00000E+00	MCC THROAT DIAMETER (IN)
	-1	33	MCC-HGIR	3.10000E-03	0.00000E+00	MCC HOT GAS INJECTOR
RESIST						

\*\*\*\*\*

\*\*\*\*\* Expert system QUERY on attribute TOPICS

\*\*\*\*\*

EXIT            Return to RBMS

\*\*\*\*\* END SESSION \*\*\*\*\*

## APPENDIX A.4

### A Sample Input File for A Batch Mode Run

N	; Debug run ?
Y	; Open an user file ?
SCLMUSER	; User interface file name
5	; No database display
?EXDR	; Go to expert system driver module
SCLM	; Execute the RBSCLM rule module
loadlm	; Enter knowledge base file name
STS61A	; Enter Mission ID
2	; Number of time slices for this mission
6	; Component ID, LOX post
THREAD	; Component location, threaded region
45	; Failure mode, low cycle fatigue
Y	; More component load
6	; LOX post
THREAD	; Threaded region
46	; High cycle fatigue
N	; No more component load
N	; No more component local load
ESASIS	; Expert system selection of indep. loads <sup>1</sup>
2	; 2 independent loads from each dep. load
3	; Based on 100% power
1.0,0.0,100	; Power level, start time, duration
1	; Percentage changes in independent loads
0	; 0% change for the first independent load
0	; for the second indep. load
0	; for the third
0	; for the fourth
0	; for the fifth
0	; for the sixth
0	; for the seventh
0	; for the eighth
0	; for the ninth
0	; for the tenth
Go	; Continue, Go to next screen of output
Go	; Continue
1.04,100.0,400	; Power, st.time, dur. of the 2nd time slice
1	; Percentage changes
0	; 0% change for the 1st indep. load
0	; 2nd
0	; 3rd
0	; 4th
0	; 5th
0	; 6th
0	; 7th
0	; 8th
0	; 9th
0	; 10th
Go	; Continue
Go	; Continue
Go	; Continue
Go	; Continue

N	; No more mission analysis
EXIT	; Exit expert system module
Y	; Save LOGFIL
?QUIT	; End LDEXPT, the load expert system

## APPENDIX A.5

INFILE for the CLSICM Load Module

9  
 64ENG-FFLE 0  
 1.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 2 1.00000E+00 1.00000E-04 0.00000E+00  
 63MCC-PCER 0  
 1.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 2 1.00000E+00 1.00000E-04 0.00000E+00  
 14LPFT-NA 0  
 9.50000E-01 0.00000E+00 0.00000E+00 0.00000E+00  
 2 9.50000E-01 9.50000E-03 0.00000E+00  
 19HPFT-EM 0  
 1.03550E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 2 1.03550E+00 1.03550E-02 0.00000E+00  
 1MR 0  
 6.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 2 6.00000E+00 1.20000E-02 0.00000E+00  
 2F-PI 0  
 3.00000E+01 0.00000E+00 0.00000E+00 0.00000E+00  
 2 3.00000E+01 2.94000E+00 0.00000E+00  
 3O-PI 0  
 1.00000E+02 0.00000E+00 0.00000E+00 0.00000E+00  
 2 1.00000E+02 5.70000E+00 0.00000E+00  
 4F-TI 0  
 3.70000E+01 0.00000E+00 0.00000E+00 0.00000E+00  
 3 3.70000E+01 3.70000E-01 0.00000E+00  
 5O-TI 0  
 1.64000E+02 0.00000E+00 0.00000E+00 0.00000E+00  
 3 1.64000E+02 1.31200E+00 0.00000E+00  
 3  
 17MCC-IEP  
 -2.99773E-03 3.00601E+03 -4.47353E-03 0.00000E+00  
 9.99974E-01 0.00000E+00 0.00000E+00 0.00000E+00  
 9.99974E-01 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00  
 40MCC-C-PO  
 1.35240E+03 1.37712E+03 2.11096E+03 0.00000E+00  
 -1.54580E+00 3.15818E+00 -1.49528E+00 0.00000E+00  
 -4.58086E-01 1.67540E+00 -7.25341E-01 0.00000E+00  
 -2.12699E-01 9.29876E-02 -4.37263E-02 0.00000E+00  
 1.33232E-01 -4.49242E-01 2.14918E-01 0.00000E+00  
 -8.32139E-01 1.03295E+00 -5.38622E-01 0.00000E+00  
 -7.91680E-04 0.00000E+00 0.00000E+00 0.00000E+00  
 -1.33380E-03 0.00000E+00 0.00000E+00 0.00000E+00  
 2.63211E-02 -1.00387E-02 2.38714E-02 0.00000E+00  
 9.25518E-03 -1.15233E-02 3.09860E-02 0.00000E+00  
 46LPFT-FL  
 1.52814E+01 -7.75352E+00 1.89340E+01 0.00000E+00  
 -4.92419E+00 5.60209E+00 -1.94178E+00 0.00000E+00  
 -2.60733E+00 3.35091E+00 -1.13986E+00 0.00000E+00

```

3.35449E-02 6.24063E-01-3.54012E-01 0.00000E+00
4.07072E-01-1.34505E+00 7.21159E-01 0.00000E+00
-1.94743E+00 1.81663E+00-6.52129E-01 0.00000E+00
-6.47263E-04-2.66550E-03 2.02884E-03 0.00000E+00
-2.20119E-03-3.49284E-03 2.56909E-03 0.00000E+00
-5.01551E-02 1.55200E-01-7.64695E-02 0.00000E+00
-1.30027E-02 7.55569E-02 0.00000E+00 0.00000E+00

```

11

12

12926MCCLNTWG

0 0.10000E+01 0.50000E-01 0.00000E+00

12

12017CHAMBER PRESSURE

0 0.00000E+00 0.00000E+00 0.00000E+00

12

12040MCC COOLANT DS PR

0 0.00000E+00 0.00000E+00 0.00000E+00

12

12927MCCLNTCN

0 0.10000E+01 0.50000E-01 0.00000E+00

12

12928MCCLNTMN

0 0.10000E+01 0.50000E-01 0.00000E+00

12

12530COOL-GF

0 0.10000E+01 0.50000E-01 0.00000E+00

12

12531HG-GF

0 0.10000E+01 0.80000E-01 0.00000E+00

12

12533HOT-SPOT

0 0.10000E+01 0.10000E+00 0.00000E+00

12

12534COOL-ENH

0 0.14000E+01 0.95000E-01 0.00000E+00

12

12536LN-KF

0 0.10000E+01 0.63000E-01 0.00000E+00

12

12540HG-W-THN

0 0.28000E-01 0.35700E-01 0.00000E+00

<sup>1</sup> Normally for a batch mode RBSCIM run, one would choose the MANUAL selection so that the number of independent loads is determined by the user. In order to select the ESASIS option, one needs to run an interactive session first to find out the number of independent loads that are required in the analysis.

APPENDIX B

LDEXPT  
VERSION 5.0

COMPOSITE LOAD SPECTRA LOAD SIMULATION SYSTEM

USER'S MANUAL

Prepared by

Hing Ho

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## Chapter 1. Composite Load Spectra

The objective of the composite load spectra is to develop generic load models to simulate the composite load spectra that are induced in space propulsion system components, representative of Space Shuttle Main Engines (SSME), such as transfer ducts, turbine blades, liquid oxygen (LOX) posts and the high pressure oxidizer turbopump (HPOTP) discharge duct (Ref. 1-6). The composite load spectra of a component is a set of correlated component load distribution functions or component load correlation fields (Ref. 7) that can be used in supplying probabilistic load information to a probabilistic design and analysis task, e. g. a component probabilistic structural analysis and fatigue life evaluation task. The correlated component loads, for example, for a turbine blade of a turbopump are the correlated turbine speed, turbine blade nodal pressures and temperatures. They are random variables and they are correlated.

The probabilistic load simulation methodology is developed for space propulsion system components. A heuristic multi-level coupled engine model is installed in the CLS code to simulate engine operation and performance, component environment, and component loads. The engine influence model developed by Rocketdyne is employed to simulate engine operation and performance. Various scaling techniques and influence models are employed to simulate the component load environment and to evaluate the component loads. The engine model and the component load models are coupled directly. Probabilistic loads are evaluated by sampling the variations of only the engine primitive variables (engine independent parameters and inlet condition variables) and component independent local variables and propagating them through the multi-level engine model.

A knowledge-based system approach (Ref. 8) is taken to develop the software for this project. This approach provides an environment that facilitates modular and incremental development. It provides links for coupling of symbolic processing and numeric processing. An intelligent database paradigm that coupled a database system with decision trees was implemented on the CLS load expert system. Text knowledge on the databases and associated queries can be assessed inside a decision tree and communicated to users during a consultation session. With the intelligent database paradigm, the system can effectively manage the large volume of engineering data and load information that are required for the load spectra synthesis.

The CLS load expert system as implemented can be used to supply load information and data of space propulsion system components. It can supply deterministic load point values and probabilistic load distribution functions. The CLS load expert system has a simple hypertext tutorial system in place. It can provide simple tutorial on space propulsion system engine and components, engine primitive variables and engine system variables, and component load

variables. The CLS engine model can be delivered and embedded into an application computer code to perform load simulation (See Ref's 6 and 9). An application computer code can also be embedded into the CLS load simulation module to perform a probabilistic analysis.

During the development of the CLS technology, various applications to the probabilistic design and analysis (PDA) of space propulsion system components were performed to test and demonstrate the methodology. Applications of the CLS technology include the probabilistic structural analysis of a space propulsion system turbine blade (Ref. 10), the probabilistic failure analysis of a space propulsion system main combustion chamber liner (Ref. 11), the LOX post probabilistic structural response analysis of cyclic thermal loading (Ref. 12), and more recently, the evaluation of fatigue damage in a space propulsion system injector element (Ref. 13), and the development of life prediction capabilities for SSME main combustion chamber liner (Ref. 14). Various linkage methods were developed to connect the CLS load simulation technology with applications such as the probabilistic structural analysis method (PSAM) code and probabilistic fatigue damage evaluation code. In the LOX post structural response analysis, an approximation of the CLS correlation field formalism using "marginal" distributions was developed and applied to the analysis. In the injector element fatigue damage evaluation, a subset of the CLS load module was embedded in the application program to evaluate component loads.

### 1.1 Probabilistic Methods

Three probabilistic methods are available for load synthesis of composite load spectra. The methods are (1) the Gaussian algebra method, (2) the RASCAL (random sampling condensation algorithm) method, and (3) the Monte Carlo method.

The Gaussian algebra method assumes all random variables are normally distributed, and the variance of a combined probabilistic load is the square sum of variances of all independent random variables. The Gaussian algebra method has provide quick evaluations and sensitivity studies for a few investigations over the course of the composite load spectra project. However, it is implemented only for the syntheses of engine system dependent loads and a few component load variables due its non generic nature of the method (i.e. separate formulas are required for the calculation of variances) and difficulty in automation of combining multi-level coupled engine loads.

The RASCAL method is a variance of the discrete probability distribution (DPD) method. It uses the simple Monte Carlo method to sample the discretized probability distribution functions of the independent random variables and combined them into a dependent random variable distribution function. The dependent random variable distribution is then condensed into a discretized probability distri-

bution function with the same number of bins as the distribution functions of independent random variables using a (RASCAL) condensation algorithm. It is versatile in that it can handle almost all types of distribution, even those without closed forms. It can be used for quick evaluation by using a small number of bins (distribution function intervals). It can also be used to generate accurate load distributions by using a large number of bins. RASCAL is the recommended method for CLS because it is good for both quick and accurate evaluation and it automatically generates the distribution functions of the composite load spectra.

The Monte Carlo method is a versatile and yet simple method for load simulation. It is recommended for load simulations required very high accuracy. At present time, only the simple straight forward Monte Carlo method is available in CLS. Advanced Monte Carlo methods can be easily implemented on CLS. They will be added to the CLS tool box as need arises. An estimation algorithm of the 95% confidence level intervals for the Monte Carlo method was implemented. Every time a distribution function is evaluated by the Monte Carlo method, the 95% confidence upper and lower bounds for the distribution are also evaluated. The estimate can also be used to provide the confidence level estimates of a RASCAL evaluation.

## 1.2 KNOWLEDGE DOMAIN

The knowledge domain for the CLS probabilistic load simulations of space propulsion system components consists of complex space propulsion system engine, components and loads information, large volume of engine variable data and engine flight and test mission history data (duty-cycle-data profile), and sophisticated probabilistic methodology and numeric computation for load simulations. A good knowledge representation that facilitates the assess of the load information and data and a suitable development environment that facilitates the coupling of knowledge and the computing process are vital to the development of the CLS knowledge-based system.

### Loads

For load information and load data, database format is used as their knowledge representation. This representation facilitates the retrieval of load data and model parameters which are critical to load simulation tasks. The load knowledge base for the CLS knowledge-based system LDEXPT (version 5.0) as shown in Fig. 1.1 includes three categories of engine loads and variables: (1) Engine inlet conditions and hardware parameters (primitive variables or system independent loads); (2) Engine system performance variables and operating condition loads (system dependent loads or variables); and (3) Component loads consisting of component internal loads, component environment and local variables. The up-to-date knowledge base has 64 primitive variables as listed in Table 1.1 and 99 system dependent variables as listed in Table 1.2, and various component loads as listed in Table 1.3 for the four components -- the turbine blade, the LOX post, the HGM transfer ducts and the HPOTP discharge duct.

Guidelines for component ID's and Load ID's are as follows:

- (1) The component ID's are assigned as follows:

<u>Component</u>	<u>ID</u>
HPFTP	1
HPOTP	2
LPFTP	3
LPOTP	4
HGM Fuel Transfer Duct	5
LOX Post	6
LOX Post, region B	7
LOX Post, region C	8
HGM Oxidizer Trans. Duct	9
HPOTP Discharge Duct	10
MCC Coolant Channel	12
Engine Primitive Variables	-1
Engine Dependent Variables	0

- (2) Engine system primitive variables or independent load variables  
ID's : 1 to 64 (See Table 1.1)
- (3) Engine system dependent load variables ID's : 1 to 99 (See  
Table 1.2)
- (4) Component related load ID's: 1 to 499 (See Table 1.3)  
Specially component static pressure ID's: 2 to 5  
component thermal load ID = 25
- (5) Component local load ID's: 500 to 599 (See Table 1.3)
- (6) Structural Component Life Model Component Load ID's: 900 to 999  
(See Table 1.3)

Figure 1.1 Composite Load Spectra Load Knowledge Base

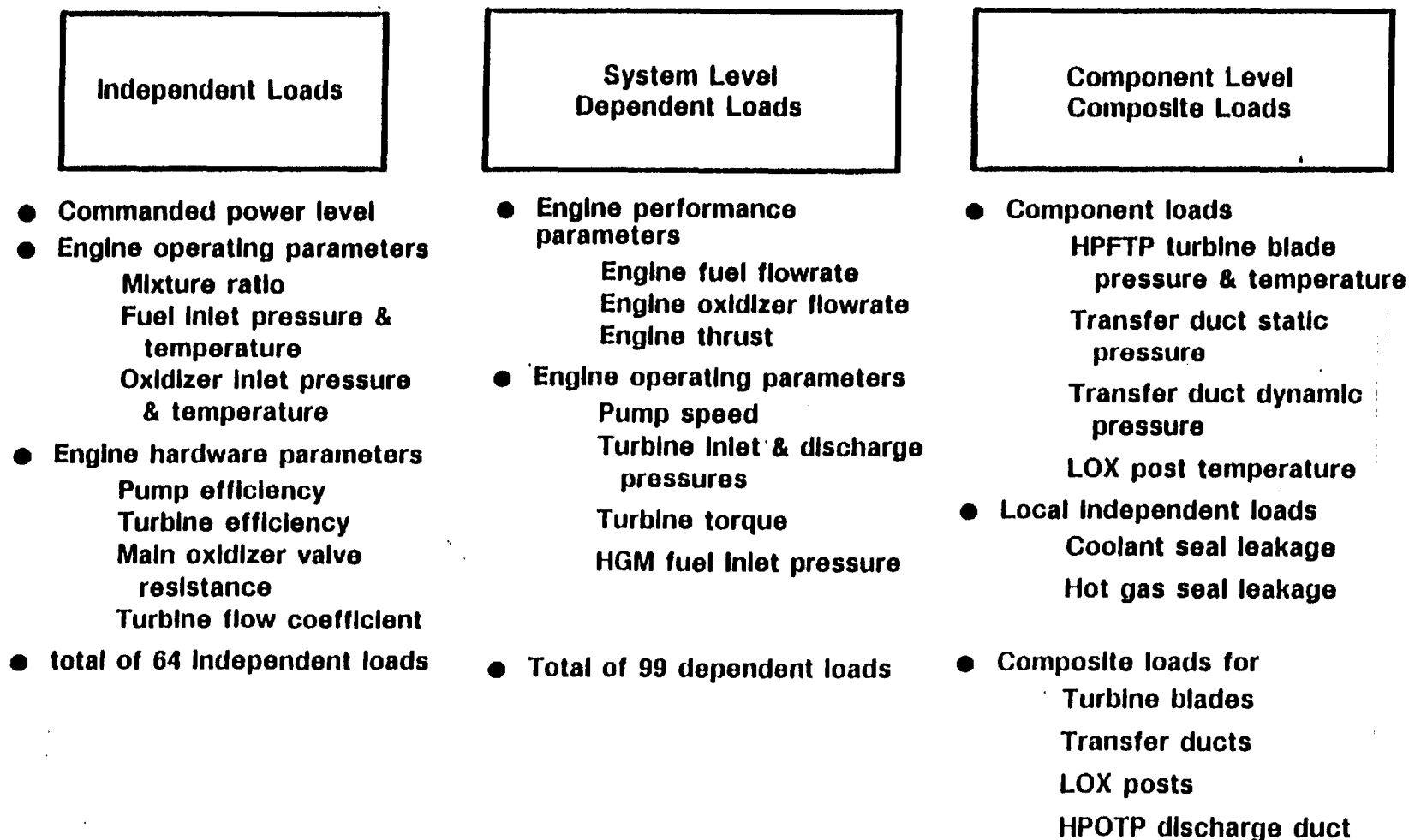


TABLE 1.1 ENGINE INFLUENCE MODEL INDEPENDENT LOADS

<u>ID</u>	<u>INDEPENDENT LOAD</u>	<u>NOMINAL VALUE</u>	<u>C.O.V.</u>
1	Commanded mixture ratio	6.0	0.002
2	Fuel inlet pressure (psia)	30.0	0.098
3	Oxidizer inlet pressure (psia)	100.0	0.057
4	Fuel inlet temperature (R)	37.0	0.010
5	Oxidizer inlet temperature (R)	164.0	0.008
6	Fuel pressurant flowrate (lbm/sec)	0.7	0.0065
7	Oxidizer pressurant flowrate (lbm/sec)	1.5968	0.015
8	HPFP cavitation (%)	1.0	0.001
9	LPFP cavitation (%)	1.0	0.001
10	LPOP cavitation (%)	1.0	0.001
11	Nozzle, mixer delta P (%)	1.1455	0.001
12	MCC throat diameter (in)	10.293	0.001
13	Nozzle exit diameter (in)	90.324	0.001
14	LPFT nozzle area (in <sup>2</sup> )	0.95	0.1
15	LPOT nozzle area (in <sup>2</sup> )	1.386	0.1
16	LPFP efficiency (%)	1.11	0.0017
17	HPFP efficiency (%)	1.00	0.008
18	LPFT efficiency (%)	1.025	0.0027
19	HPFT efficiency (%)	1.0355	0.01
20	LPOP efficiency (%)	1.14	0.005
21	HPOP efficiency (%)	1.02	0.004
22	PBP efficiency (%)	1.022	0.0016
23	LPOT efficiency (%)	1.022	0.02
24	HPOT efficiency (%)	1.0152	0.01
25	HPOP cavitation (%)	1.0	0.001
26	LPFP head coefficient (%)	0.99	0.007
27	HPFP head coefficient (%)	1.0237	0.008
28	LPOP head coefficient (%)	1.0	0.013
29	PBP head coefficient (%)	1.155	0.004
30	MCC OX dome resistance	0.0384	0.02
31	HGM OX side resistance	0.0032	0.05
32	HGM fuel side resistance	0.0275	0.05
33	MCC Hot Gas injector resistance	0.0031	0.025
34	HGM coolant OX side resistance	0.1040	0.025
35	LPOP disch duct resistance	0.0021	0.01
36	Primary faceplate resistance	15.0	0.075
37	Secondary faceplate resistance	11.17	0.075
38	LPFT seal resistance	7283.0	0.001
39	HPOT coolant circuit resistance	2066.0	0.001
40	HPFP disch duct resistance	0.0123	0.01
41	Main fuel valve resistance	0.0138	0.064
42	Main oxidizer valve resistance	0.0107	0.064
43	MCC OX injector resistance	0.0602	0.025
44	MCC cooling jacket delta pressure	1.031	0.001

TABLE 1.1 (cont's)

<u>ID</u>	<u>INDEPENDENT LOAD</u>	<u>NOMINAL VALUE</u>	<u>C.O.V.</u>
45	OPB fuel injector resistance	0.685	0.01
46	FPB fuel injector resistance	0.155	0.01
47	LPFT disch duct resistance	0.104	0.01
48	LPFT inlet duct & F-7 resistance	0.5689	0.01
49	PBP inlet duct resistance	0.134	0.01
50	Coolant control valve resistance	0.05568	0.088
51	Baffle flow coefficient	0.95	0.001
52	PB fuel supply duct resistance	0.0071	0.01
53	Nozzle delta P (%)	0.6889	0.001
54	HPOTP turb-end bearing coolant res	65000.0	0.001
55	MCC combustion efficiency (MCC C*)	1.0004	0.001
56	Nozzle heat load (%)	0.884	0.001
57	MCC chamber heat load (%)	0.7932	0.001
58	HPFT flow coefficient	1.0125	0.01
59	HPOT flow coefficient	0.9741	0.01
60	Preburner combustion efficiency (%)	0.98	0.001
61	Mixer delta P (%)	1.0	0.001
62	LOX flow constant (c2)	2.8952	0.001
63	MCC pc measurement error (%)	1.0	0.001
64	Engine fuel flowmeter error (%)	1.0	0.001

TABLE 1.2 ENGINE INFLUENCE MODEL DEPENDENT LOADS

<u>ID</u>	<u>DEPENDENT LOAD</u>	<u>NOMINAL VALUE</u>	<u>C.O.V.</u>
1	Engine altitude thrust (lbf)	471067.522	0.005
2	HPOTP speed (rpm)	27239.145	0.008
3	HPFTP speed (rpm)	34517.69	0.008
4	HPOP disch pressure (psia)	1595.403	0.0089
5	PB pump disch pressure (psia)	7185.46	0.0098
6	HPFP disch pressure (psia)	6161.829	0.009
7	OPB chamber pressure (psia)	5039.427	0.0129
8	FPB chamber pressure (psia)	4876.04	0.0137
9	Engine oxidizer flowrate (lbm/sec)	894.34	0.0062
10	Engine fuel flowrate (lbm/sec)	149.06	0.0069
11	Oxidizer pressurant flowrate (lbm/sec)	1.5968	0.015
12	Fuel pressure flowrate (lbm/sec)	0.6996	0.0065
13	OPB oxidizer valve position (%)	0.6495	0.0147
14	FPB oxidizer valve position (%)	0.7652	0.0135
15	MCC oxidizer injector pressure (psia)	3540.82	0.0086
16	MCC Hot Gas injector pressure (psia)	3237.36	0.0064
17	MCC injector end pressure (psia)	3006.0	0.0058
18	HPOP inlet pressure (psia)	380.07	0.0228
19	HPFP inlet pressure (psia)	226.084	0.0263
20	HPOP disch temperature (R)	190.195	0.002
21	HPFP disch temperature (R)	94.904	0.0114
22	MEV disch temperature (R)	95.491	0.0114
23	PB pump disch temperature (R)	203.377	0.0025
24	HPOP inlet temperature (R)	169.425	0.006
25	HPFP inlet temperature (R)	42.472	0.0019
26	LPOTP speed (rpm)	5042.8	0.008
27	LPFTP speed (rpm)	15850.64	0.0087
28	HPOT disch temperature (R)	1352.533	0.0274
29	HPFT T/D disch temperature (R)	1625.723	0.0193
30	OPB oxidizer valve resistance	130.79	0.098
31	FPB oxidizer valve resistance	13.18	0.15
32	Oxidizer pressurant pressure (psia)	3439.598	0.0092
33	Fuel pressurant pressure (psia)	3348.296	0.0079
34	Oxidizer pressurant temperature (R)	838.0	0.0245
35	LPFT disch temperature (R)	472.95	0.0125
36	LPOP suction specific speed (NSS)	8054.341	0.02
37	LPFP suction specific speed (NSS)	19738.26	0.02
38	HPOP suction specific speed (NSS)	11295.08	0.0185
39	HPFP suction specific speed (NSS)	6017.04	0.024
40	MCC coolant disch pressure (psia)	4840.48	0.0108
41	LPOT torque (ft-lbf)	1565.124	0.0159
42	LPFT torque (ft-lbf)	996.605	0.0182
43	HPOT torque (ft-lbf)	4436.78	0.0108
44	HPFT torque (ft-lbf)	9452.388	0.0142

TABLE 1.2 (cont's)

<u>ID</u>	<u>DEPENDENT LOAD</u>	<u>NOMINAL VALUE</u>	<u>C.O.V.</u>
45	LPOT flowrate (lbm/s)	176.17	0.01
46	LPFT flowrate (lbm/s)	26.46	0.0175
47	HPOT flowrate (lbm/s)	58.95	0.01
48	HPFT flowrate (lbm/s)	158.92	0.0107
49	LPOT inlet pressure (psia)	3947.348	0.0895
50	LPFT inlet pressure (psia)	4508.63	0.0105
51	HPOT inlet pressure (psia)	5019.85	0.00875
52	HPFT inlet pressure (psia)	4857.17	0.0095
53	LPOT inlet temperature (R)	190.195	0.002
54	LPFT inlet temperature (R)	489.121	0.0122
55	HPOT inlet temperature (R)	1501.062	0.0266
56	HPFT inlet temperature (R)	1812.757	0.0186
57	LPOT disch pressure (psia)	414.28	0.0208
58	LPFT disch pressure (psia)	3403.035	0.0076
59	HPOT disch pressure (psia)	3318.146	0.0066
60	HPFT disch pressure (psia)	3439.885	0.0067
61	LPOT power (bhp)	1502.269	0.024
62	LPFT power (bhp)	3013.01	0.027
63	HPOT power (bhp)	23012.439	0.0155
64	HPFT power (bhp)	62192.2	0.0175
65	HGM inlet pressure, fuel (psia)	3356.87	0.0075
66	HGM inlet pressure, OX (psia)	3302.345	0.0075
67	Oxidizer T/D dynamic pressure (psia)	16.6	0.01
68	Oxidizer T/D flow velocity (ft/s)	454.81	0.01
69	Fuel T/D dynamic pressure (psia)	25.72	0.01
70	Fuel T/D flow velocity (ft/s)	578.4	0.01
71	HPOT mixture ratio (O/F)	0.7323	0.034
72	HPFT mixture ratio (O/F)	0.9267	0.0227
73	OPB power (bhp)	168661.0	0.02
74	FPB power (bhp)	544895.0	0.02
75	MCC power (bhp)	1.2473E+07	0.005
76	OPB OX in manifold pressure (psia)	5927.91	0.013
77	OPB fuel in manifold pressure (psia)	5360.543	0.0085
78	FPB OX in manifold pressure (psia)	6088.94	0.0137
79	FPB fuel in manifold pressure (psia)	5400.416	0.0088
80	PBP disch, PB OX supply temp (R)	203.377	0.0025
81	Mixer disch, PB fuel supply temp (R)	275.777	0.0045
82	Fuel HGM velocity (ft/s)	1322.532	0.01
83	Fuel HGM dynamic pressure (psia)	132.983	0.01
84	LOX HGM velocity (ft/s)	214.13	0.01
85	LOX HGM dynamic pressure (psia)	3.737	0.01
86	OPB fuel dynamic pressure (psia)	0.1978	0.01
87	OPB fuel flow velocity (ft/s)	367.214	0.01
88	FPB fuel dynamic pressure (psia)	44.647	0.01

TABLE 1.2 (cont's)

<u>ID</u>	<u>DEPENDENT LOAD</u>	<u>NOMINAL VALUE</u>	<u>C.O.V.</u>
89	FPB fuel flow velocity (ft/s)	411.96	0.01
90	HPOP disch dynamic pressure (psia)	230.658	0.01
91	HPOP disch velocity (ft/s)	174.213	0.0052
92	HPOP head rise (ft)	7545.048	0.0095
93	HPFP disch dynamic pressure (psia)	123.277	0.01
94	HPFP disch velocity (ft/s)	469.11	0.0055
95	HPFP head rise (ft)	174050.04	0.0085
96	PBP disch dynamic pressure (psia)	32.48	0.01
97	PBP disch velocity (ft/s)	65.14	0.0052
98	HGM coolant inlet pressure (psia)	3346.037	0.0074
99	Engine nozzle exit velocity (ft/s)	14562.83	0.01

TABLE 1.3 Component Load ID's and Load Names

<u>Component-ID</u>	<u>Load-ID</u>	<u>Component Load Name</u>
		*** Turbine Blade Loads ***
1	1	HF-CFG , HPFTP centrifugal force
1	2	HF-MP-T1 , HPFTP T/B pressure
1	3	HF-MP-T2
1	4	HF-MP-A1
1	5	HF-MP-A2
1	6	HF-T-T1
1	7	HF-T-T2
1	8	HF-T-A1
1	9	HF-T-A2
1	10	HF-MN-T1
1	11	HF-MN-T2
1	12	HF-MN-A1
1	13	HF-MN-A2
1	14	HF-H-T1
1	15	HF-H-T2
1	16	HF-H-A1
1	17	HF-H-A2
1	18	HF-T-DP1
1	19	HF-T-DP2
1	20	HF-M-DP1
1	21	HF-M-DP2
1	22	HF-H-DP1
1	23	HF-H-DP2
1	25	TB-R2-T , HPFTP T/B temperature
1	26	MAX-WG-T , T/B hot gas wall max. temp.
1	27	MIN-WC-T , T/B coolant wall min. temp.
1	28	ISO-M1-T , T/B first mix gas temp.
1	29	ISO-M2-T , T/B second mix gas temp.
1	44	TB2519-P , T/B 2519 nodes FEM nodal pr.
1	50	TB5000-T , T/B 5000+ nodes FEM temp.
1	52	WC5000-T , Coolant wall temp. for 5000+
1	530	COOL-GF , T/B coolant geometry factor
1	531	HF-GF , T/B hot gas geometry factor

TABLE 1.3 (cont's)

<u>Component-ID</u>	<u>Load-ID</u>	<u>Component Load Name</u>
		*** HGM Fuel Transfer Duct Loads ***
5	2	HFTD-S-P , HGM f. tr. duct, static pr.
5	5	HFTD-OSP outer diameter static pr.
5	25	TDUCT-T
5	26	MAX-WG-T
5	27	MIN-WC-T
5	33	HFTD-F-P , fluctuating pressure
5	530	COOL-GF , HGM fuel Duct coolant GF
5	531	HG-GF
		*** LOX Post Loads ***
6	2	LOXPTISP , LOX Post, top in. static pr.
6	3	LOXPMISP
6	4	LOXPBISP
6	5	LOXPMOSP
6	6	LOXPBOSP
6	25	LOXP-A-T , LOX Post temp. region A
6	26	MAX-WG-T
6	27	MIN-WC-T
6	33	LOXP-FFP
6	530	COOL-GF
6	531	HG-GF
6	532	GAP-SS
6	535	HG-DENS , LOX Post hot gas density
6	536	HAY-KF , LOX post Haynes conductivity
7	25	LOXP-B-T
7	26	MAX-WG-T
7	27	MIN-WC-T
8	25	LOXP-C-T
8	26	MAX-WG-T
8	27	MIN-WC-T
		*** HGM Oxidizer Tr. Duct Loads ***
9	2	HOTD-S-P
9	5	HOTD-OSP
9	33	HOTD-F-P
		*** HPOTP Discharge Duct Loads ***
10	2	HODD-S-P
10	33	HODD-F-P
		*** MCC Coolant Channel Loads ***
12	530	COOL-GF
12	531	HG-GF
12	533	HOT-SPOT
12	534	COOL-ENH
12	536	LN-KF
12	540	HG-W-THN

TABLE 1.3 (cont's)

<u>Component-ID</u>	<u>Load-ID</u>	<u>Component Load Name</u>
		*** SCLM Component Loads ***
6	945	LPTHRLCF
6	946	LPTHRHCF
10	933	HPOTPF
12	925	MCC-CC-T
12	926	MCCLNTWG
12	927	MCCLNTCN
12	928	MCCLNTMN
12	940	MCC-C-PI

### Multi-Level Coupled Engine Model

Engine model and component load models are needed to evaluate the simulated probabilistic loads. A multi-level engine model as shown in Fig. 1.2 that couples the engine model with various component load models was implemented to correlate component loads with the engine operating and performance variables and engine (hardware and inlet conditions) primitive variables. The implemented CLS load models are as listed in Fig. 1.3: the engine system model is a probabilistic influence model, various component load models including the generic static pressure scaling model, the generic probabilistic thermal load model, various turbine blade load scaling models, and LOX post transient thermal load model. Load simulation routines were developed for these load models and implemented in the load simulation module ANLOAD. Generic load models were developed whenever possible so that they could be applied to different system components without remodeling the load again. In such cases, the component specific data and information of the component loads are stored in the knowledge base. These component specific information will be retrieved and supplied to the generic model when the component load is evaluated.

Figure 1.2 CLS Multi-Level Coupled Engine Model

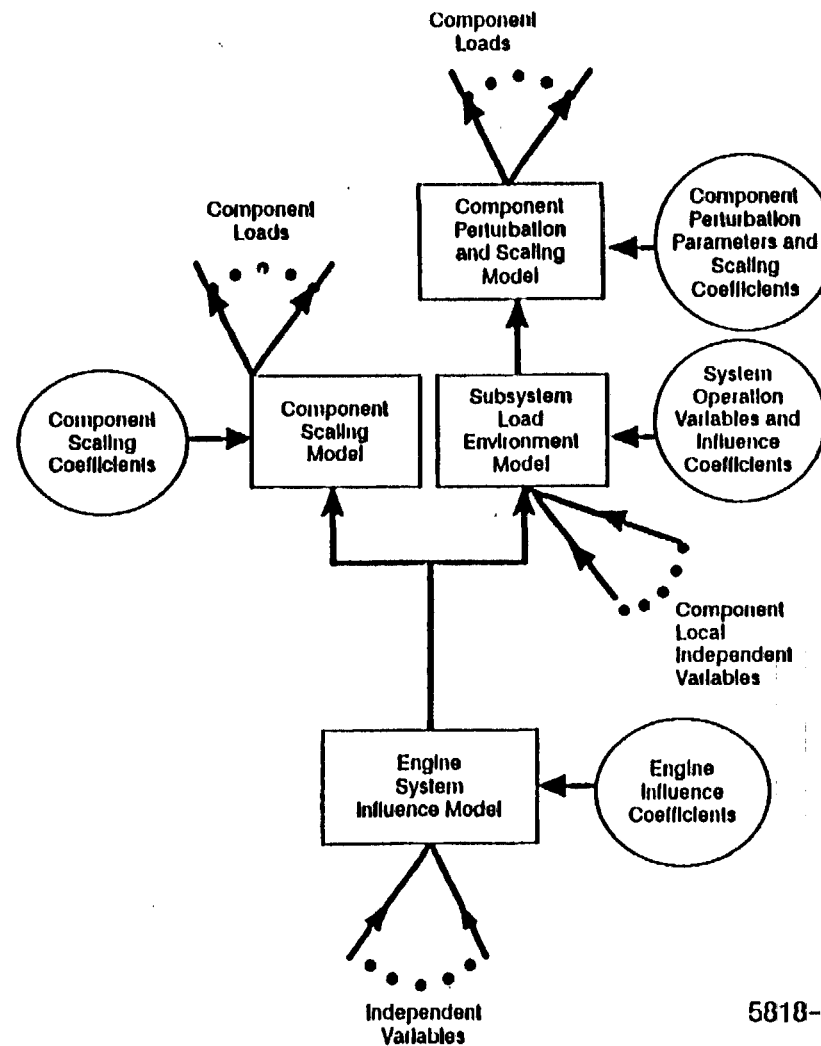


Figure 1.3 Composite Load Spectra Load Model Knowledge Base

**Engine System  
Model**

- Load distributions
  - Means
  - Coefficients of variation
  - Distribution types
  - Nominal value coefficients
- Probabilistic Influence model
  - Influence coefficients
  - 1  $\sigma$  gain values

**Component Load  
Models**

- Generic static pressure scaling model
- Generic probabilistic thermal load model
- Generic turbine blade pressure load model
  - Tip, mean & hub cross section pressures
  - Turbine blade pressure interpolation scheme
- HPFTP 2nd stage turbine blade pressure & temperature loads
  - 2519 nodes geometry model
  - Reference nodal pressures & temperatures
- Turbine blade dynamic pressure load model
- Duct dynamic pressure load model
  - Transfer ducts, LOX posts, HPOTP discharge duct
- Transient LOX post thermal load model
- Vibration model



### 1.3 CLS Load Simulation

Load simulation is performed in the CLS load simulation module ANLOAD. The process as delineated in Fig. 1.4 is carried out in the following steps: (1) Sample point values of the primitive variables and independent component local variables are selected by a probabilistic method chosen for the analysis; (2) Deterministic point values of loads are evaluated by the engine load module CLSICM based on the sampled point values of the primitive variables and the independent component local variables passed to the engine load module; (3) The calculated load values are passed back to the ANLOAD driver and saved for later processing; (4) Repeat step (1) to (3) until the number of simulation are satisfied; (5) The calculated load values are processed into distribution functions and the statistical data of the loads are evaluated.

The CLS engine model is an influence model. Various component load models are implemented using scaling technique. These models including the engine influence model essentially evaluate the loads by calculating the changes of the loads as a result of the changes in the engine primitive variables and other independent variables, i.e. as a result of the changes of the engine hardware parameters and inlet conditions and the changes of component material properties and geometry factors. The mean values of the loads, either the system dependent load variables or the component loads, are evaluated separately. The nominal value of an engine system dependent load is calculated with a third order polynomial as a function of controlled power level. The transient spikes seen in some engine dependent loads such as the HPFTP turbine inlet temperature during a start transient are either obtained from the SSME data stored in load object functions, or calculated from a transient spike model. The component load mean values are either obtained from reference load values or evaluated with a component mean value scaling model.

Load simulation can be carried out for an engine steady state operation or a mission history of an engine flight or test. A typical SSME flight mission history as shown in Fig. 1.5 consists of an engine start transient lasted about 5 seconds, a steady state at 104% RPL lasted 470 seconds including a 2 minutes solid firing period at the beginning of the steady state with a throttled down to 65% RPL interval, and an engine shutdown transient lasted about 60 seconds. CLS has in file the mission history profiles of a SSME flight STS61-A and several tests. These mission history profiles can be retrieved with the CLS expert system and used in a duty cycle mission history load simulation.

The engine influence model is well tested for engine steady state operation and performance evaluation. It is also tested to be well represented of the engine from power level of 65% RPL to power level of 109% with reasonable accuracy. In CLS implementation, during the transient states, engine start transient and shutdown transient, a quasi-steady-state approximation is employed. An

Figure 1.4 Architecture of the CLS Load Simulation Module ANLOAD

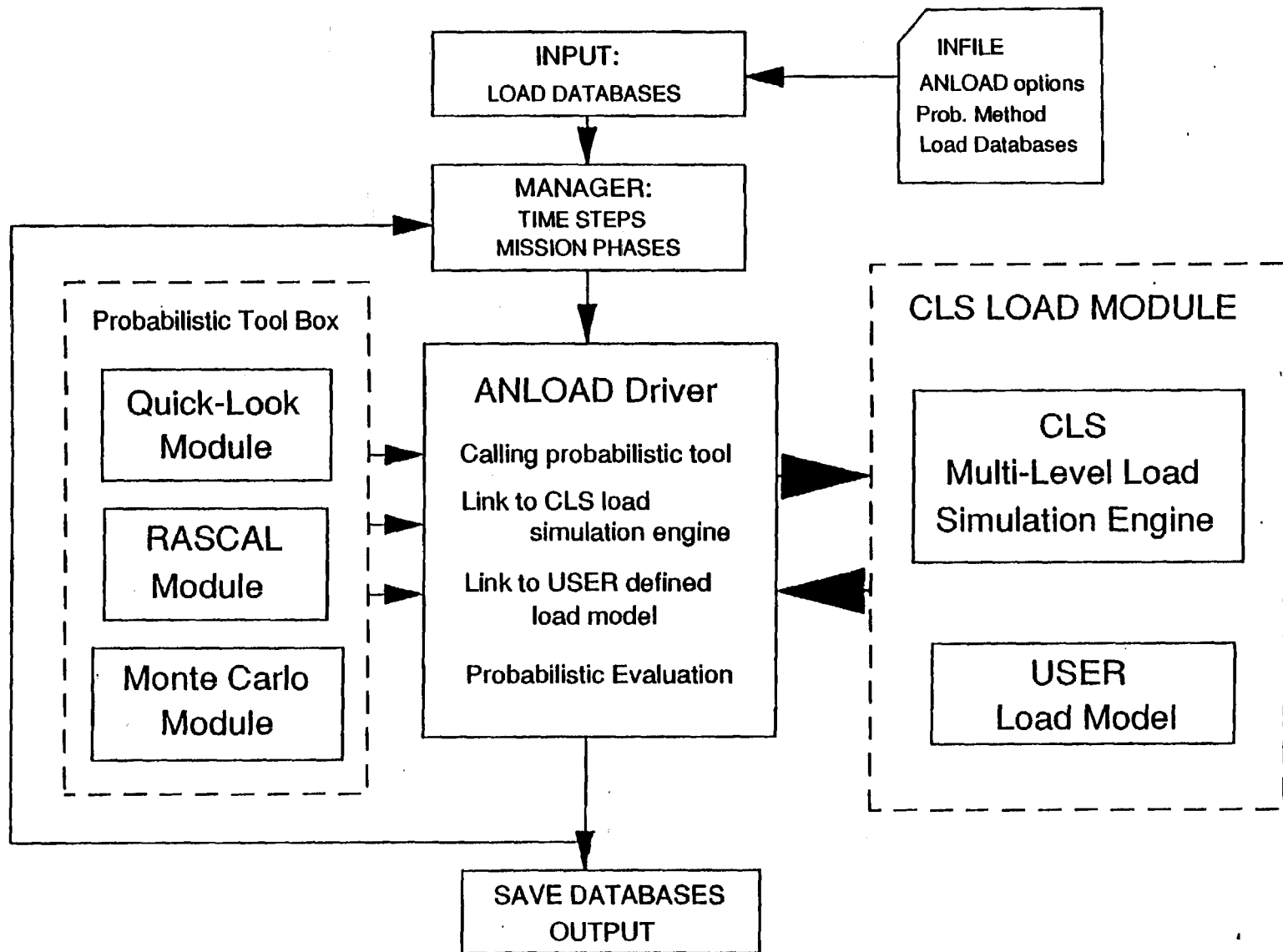
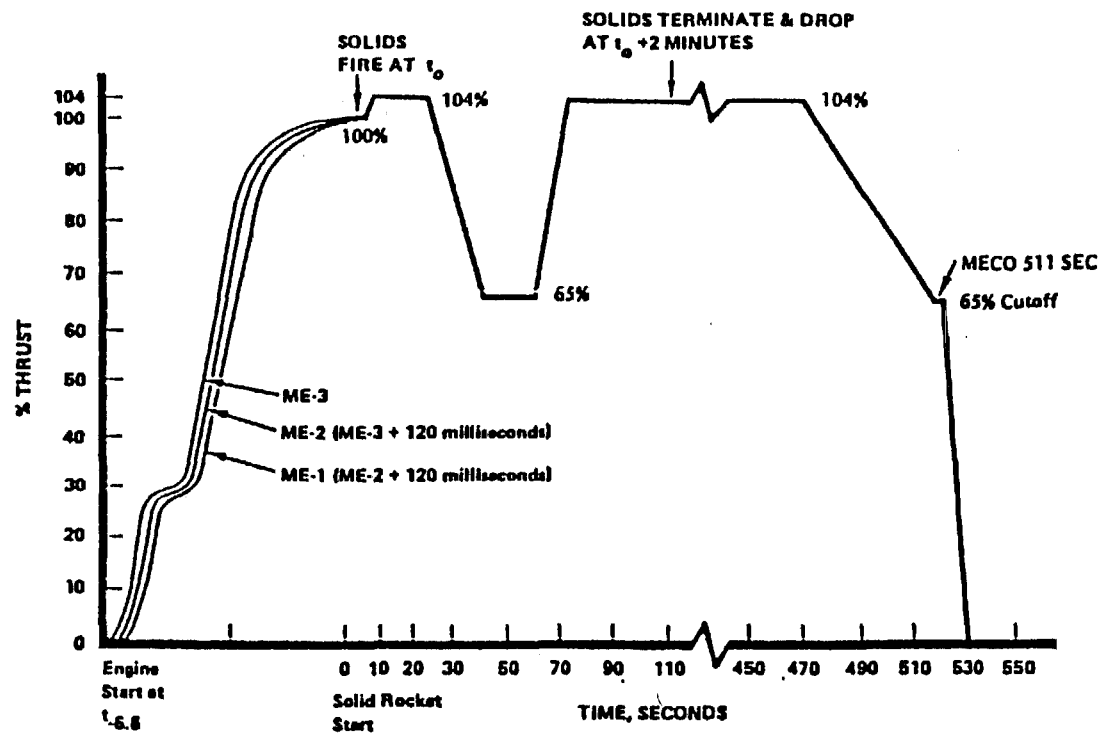


Figure 1.5 A SSME Duty Cycle Mission Flight Profile



assumption is made that all engine and component loads can be modeled as steady-state loads over a sufficiently small time step. The coefficients of variations, i.e. the ratio of the standard deviation and the mean of the loads, remain constant throughout the transient states. For loads calculated by an influence model, the influence model values are used for the simulated load values for power level between 65% to 109% RPL. Load values at power levels below 65% are extrapolated based on the influence model value at 65% RPL.

During the start transient phase, there are engine loads that are significantly deviated from nominal behavior due to the nonequilibrium operation of the engine. Temperature spikes and to a less degree pressure spikes are seen by the turbine blade, transfer ducts and LOX posts. These spikes can be modeled in load simulation module as a triangular spike superimposed on top of the quasi-steady-state load curve. The empirical mean spike transient functions of these loads based on SSME spike data are stored in a routine of transient load object functions and will be activated if so chosen when those loads are simulated. They are documented in the engine and component load models section.

There is a rare event model using Poisson arrival model to simulate a random spike (Ref. 4). Since there is no need for it this time, it will stay as a undocumented CLS feature for now.

## Chapter 2. The Architecture of CLS Load Expert System LDEXPT

The CLS load expert system LDEXPT as shown in Fig. 2.1 has two main modules: the knowledge base module and the rule base module. The functions of the knowledge base module are the database management (DBMS), the duty-cycle-data processing (PROFDP) and the knowledge base system I/O (KBIO). The functions of the rule base module are the expert system consultation task processing (Rule Modules), the user interface with the rule base tools (Rule Base Tools), and the load simulation (ANLOAD). Since the load simulation module ANLOAD is a large module and it runs in batch mode, ANLOAD is installed as a stand-alone module.

### DBMS

The database management system is a genuine database system. It facilitates the building and maintenance of engine data and knowledge databases. It provides uniform procedures for data and information storage and retrieval. Its usage benefits in avoidance of data redundancy and maintenance of data integrity.

### PROFDP

PROFile Data Processing (PROFDP) is a duty-cycle-data processing module. It is used to store (to a file) and retrieve engine mission data in a piecewise linear form. The mission data for either a test or a flight includes duty cycle power profile, controlled fuel to oxidizer mixture ratio, fuel inlet pressure and temperature, and liquid oxygen (LOX) inlet pressure and temperature.

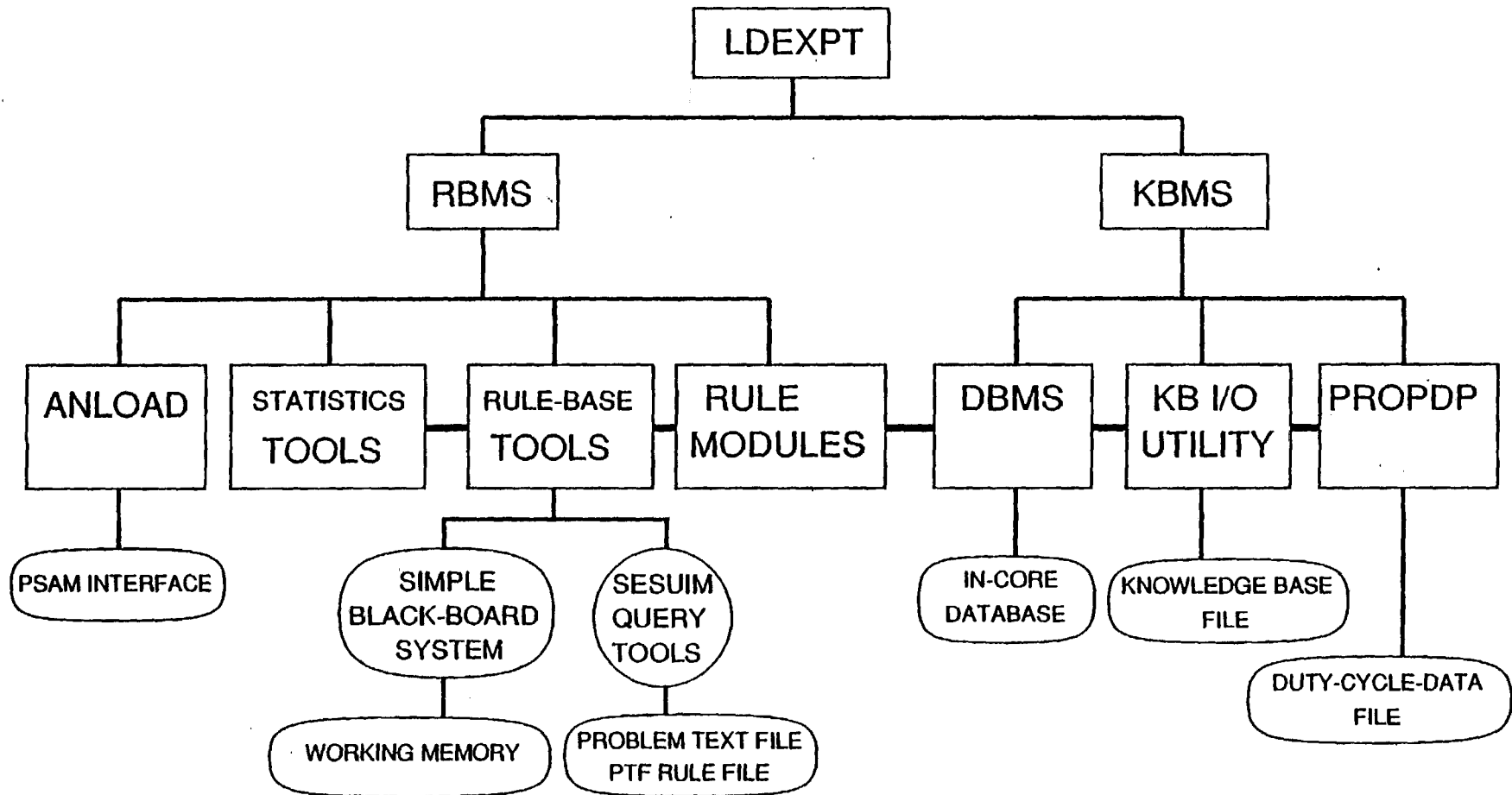
### KBIO

KBIO is the Knowledge Base Input/Output module. Its main function is to retrieve a database from the knowledge base file into in-core memory, and to save a database to the knowledge base file when it is created or updated. Both the DBMS and PROFDP modules use the I/O routines of KBIO to precess the files.

### Rule Modules and Rule Base Tools

Rule modules are routines, each of which performs a certain consultation or data retrieval tasks. Each routine is a decision tree that can interface with user using the rule base query tool. Some rule modules can also call on other rule modules to perform the required tasks. The query panels presented to users on a computer screen are stored in the knowledge base problem text file and retrieved with the query tool. A query panel usually consists of knowledge about a database and an associated query. The query

Figure 2.1 CLS Load Expert System LDEXPT Version 5.0 Code Structure



panels are activated by "buttons", most the time they are the field names of the key fields of the database.

The rule module tasks consist of the following categories: (1) retrieval of load information and data; (2) simple engine system and component load model simulations; and (3) preparation of an input file for a mission load simulation for ANLOAD or other applications. Each database is retrieved by a rule module. The field values of a retrieved database record are stored into the proper variables used consistently through out the load expert system code LDEXPT including ANLOAD. A deterministic engine influence model is available for the evaluation of engine system dependent load variables. A quick look model using the Gaussian algebra method is available for evaluation of probabilistic engine system dependent load variables.

### ANLOAD

ANLOAD is the load simulation module that performs a single time step or a duty cycle mission history simulation of the probabilistic engine system and component loads. ANLOAD is a stand-alone load simulation program. The engine load module CLSICM simulating the multi-level coupled engine model is embedded in ANLOAD. An input file named INFILE is required to run ANLOAD. All load information and engine data are supplied to ANLOAD with INFILE. This illustrates the loosely coupling scheme of coupling the symbolic processes and the numeric processes employed in the CLS system. The consultation rule module ANLDIN interfaces with the user and prepares an input file for the user's load simulation task. The only connection of the load simulation (a numeric process) module to the load expert system modules is through the input file INFILE. The detail descriptions of input variables and input format are presented in Appendix I.

In the next chapter "GETTING STARTED", lists of file names of the executable and their associated files for the CLS modules are presented. Procedures of how to get started for these modules are delineated. In the chapters following that, each module is described in detail. The implementation of the module and programming information are presented.

### Chapter 3. GETTING STARTED

The CLS executable modules and files listed below are required to perform CLS load expert system consultations, load simulations and auxiliary operations.

#### 3.1 LDEXPT

CLS load expert system LDEXPT consists of the rule base management system and knowledge base management system.

TABLE 3.1 LDEXPT Files

<u>File Type</u>	<u>File Name</u>	<u>Description</u>
Executable	ldrbms52	CLS expert system RBMS & KBMS
makefile	ldrbms52.mak	See listing 3.1
Knowledge Base (KB) Files	loadlm2	CLS knowledge base file storing all load databases
	SSMEDcd	SSME duty cycle mission history profile file
KB Auxiliary Text Files	LDKBPTF	CLS knowledge base problem text file
	LDKBRUL	CLS knowledge base rule file
	TBCOEF	CLS turbine blade pressure scaling coefficients file
Utility File	LOGFIL	CLS logfile recording an in progress expert system session; Saved LOGFIL file needs to be rename before next execution of ldrbms52

# Listing 3.1 ldrbms52.mak

```

LDEXPT    = ldexpt.o rbms.o kbms.o sesuim.o dsbini.o dismle.o\
           disfit.o dismom.o
RBDRIV    = rbdri2.o rbqlm2.o rbsicm4.o rbssm2.o rbtbin.o\
           rbfpsp2.o rbidpl2.o rbdepl.o rbtbcl.o rbdcd.o rbicgn.o\
           rbthcl2.o rbscth2.o rbicth2.o rbscbd.o rbddyn2.o\
           rbclfp2.o rbduct.o rbslrc.o rbsclm3.o rbpsam.o rbbdl2.o
RBUTILITY= rbaccs.o rbsccl2.o rblgda.o slsclm2.o psdpr.o corlen.o\
           fitstd.o rbgfl.o inprep4.o inprof.o grsproc.o grspmn.o\
           grsptt.o lstdat.o gamma.o grspkv.o hgdenf.o loxdenf.o\
           aconv.o grspln.o bbpost.o storln.o clloxp2.o\
           clhpotpdd2.o clhodd.o clmccl.o clobjs.o bbswap.o\
           istswp.o tblswp.o bbstat.o
DBMS       = dbms.o dbdpkf.o dbslrc.o dbuptb.o dbdlrc.o dbcertb.o\
           dbbuke.o dbcoppy.o dblskf.o dblstb.o dbinld.o dbinf2.o\
           dbrddc.o dbsvtb.o
DBUTILITY= dbgein.o dbdpda.o dbwrfd.o dbwrrc.o dbpost.o dbgeky.o\
           dbrdda.o dbrdfd.o dbrdkd.o dbsttb.o sorkey.o shls02.o\
           dbswit.o pcttoz.o
KBIO       = opnfl.o opnofl5.o findfl.o findgr2.o dbputg.o getr.o\
           getdat.o ldexp5.o putblk.o putvv.o fixnr.o goendf.o\
           gogblk.o gethdf5.o gethdg_50.o scanf.o sgaddr.o\
           trnfrm.o prpage.o prpgii.o
KBQUERY    = query.o prlf.o rinput.o getatt.o fptfsc.o why.o
LIBS       = -lm -lf77
ldrbms52 : $(LDEXPT) $(KBIO) $(KBQUERY) \
           $(RBDRIV) $(RBUTILITY) $(DBMS) $(DBUTILITY)
           f77 -o ldrbms52 $(LDEXPT) $(KBIO) $(KBQUERY) \
           $(RBDRIV) $(RBUTILITY) $(DBMS) $(DBUTILITY) \
           $(LIBS)
opnofl5.o : opnofl5.f
           f77 -c opnofl5.f
ldexpt.o : ldexpt.f
           f77 -c ldexpt.f
rbms.o : rbms.f
           f77 -c rbms.f
kbms.o : kbms.f
           f77 -c kbms.f
sesuim.o : sesuim.f
           f77 -c sesuim.f
dsbini.o : dsbini.f
           f77 -c dsbini.f
query.o : query.f
           f77 -c query.f
prlf.o : prlf.f
           f77 -c prlf.f
why.o : why.f
           f77 -c why.f
ldexp5.o : ldexp5.f
           f77 -c ldexp5.f

```

Listing 3.1 (cont's, 2 of 6 pages)

```
aconv.o : aconv.f
        f77 -c aconv.f
bbpost.o : bbpost.f
        f77 -c bbpost.f
bbswap.o : bbswap.f
        f77 -c bbswap.f
istswp.o : istswp.f
        f77 -c istswp.f
tblswp.o : tblswp.f
        f77 -c tblswp.f
bbstat.o : bbstat.f
        f77 -c bbstat.f
corlen.o : corlen.f
        f77 -c corlen.f
dismle.o : dismle.f
        f77 -c dismle.f
disfit.o : disfit.f
        f77 -c disfit.f
dismom.o : dismom.f
        f77 -c dismom.f
fitstd.o : fitstd.f
        f77 -c fitstd.f
fptfsc.o : fptfsc.f
        f77 -c fptfsc.f
gamma.o : gamma.f
        f77 -c gamma.f
getatt.o : getatt.f
        f77 -c getatt.f
getdat.o : getdat.f
        f77 -c getdat.f
gethdf5.o : gethdf5.f
        f77 -c gethdf5.f
gethdg_50.o : gethdg_50.f
        f77 -c gethdg_50.f
getr.o : getr.f
        f77 -c getr.f
grspkv.o : grspkv.f
        f77 -c grspkv.f
grspln.o : grspln.f
        f77 -c grspln.f
grspmn.o : grspmn.f
        f77 -c grspmn.f
grsprc.o : grsprc.f
        f77 -c grsprc.f
grsptt.o : grsptt.f
        f77 -c grsptt.f
inprep4.o : inprep4.f
        f77 -c inprep4.f
```

Listing 3.1 (cont's, 3 of 6)

```
inprof.o : inprof.f
          f77 -c inprof.f
lstdat.o : lstdat.f
          f77 -c lstdat.f
pcttoz.o : pcttoz.f
          f77 -c pcttoz.f
prpage.o : prpage.f
          f77 -c prpage.f
prpgii.o : prpgii.f
          f77 -c prpgii.f
psdpr.o : psdpr.f
          f77 -c psdpr.f
findfl.o : findfl.f
          f77 -c findfl.f
findgr2.o: findgr2.f
          f77 -c findgr2.f
rinput.o : rinput.f
          f77 -c rinput.f
shls02.o : shls02.f
          f77 -c shls02.f
sorkey.o : sorkey.f
          f77 -c sorkey.f
storln.o : storln.f
          f77 -c storln.f
putblk.o : putblk.f
          f77 -c putblk.f
putvv.o : putvv.f
          f77 -c putvv.f
opnfl.o : opnfl.f
          f77 -c opnfl.f
fixnr.o : fixnr.f
          f77 -c fixnr.f
goendf.o : goendf.f
          f77 -c goendf.f
gogblk.o : gogblk.f
          f77 -c gogblk.f
scanpf.o : scanpf.f
          f77 -c scanpf.f
sgaddr.o : sgaddr.f
          f77 -c sgaddr.f
trnfrm.o : trnfrm.f
          f77 -c trnfrm.f
rbdriv2.o: rbdriv2.f
          f77 -c rbdriv2.f
rbaccs.o : rbaccs.f
          f77 -c rbaccs.f
rbpsam.o : rbpsam.f
          f77 -c rbpsam.f
```

Listing 3.1 (cont's, 4 of 6)

```
slsclm2.o: slsclm2.f
    f77 -c slsclm2.f
rbqlm2.o : rbqlm2.f
    f77 -c rbqlm2.f
rbsclm3.o: rbsclm3.f
    f77 -c rbsclm3.f
clloxp2.o: clloxp2.f
    f77 -c clloxp2.f
clhodd.o : clhodd.f
    f77 -c clhodd.f
clhpotpdd2.o: clhpotpdd2.f
    f77 -c clhpotpdd2.f
clmccl.o : clmccl.f
    f77 -c clmccl.f
clobjs.o : clobjs.f
    f77 -c clobjs.f
hgdenf.o : hgdenf.f
    f77 -c hgdenf.f
loxdenf.o: loxdenf.f
    f77 -c loxdenf.f
rbsicm4.o: rbsicm4.f
    f77 -c rbsicm4.f
rbssm2.o : rbssm2.f
    f77 -c rbssm2.f
rbtbin.o : rbtbin.f
    f77 -c rbtbin.f
rbidpl2.o : rbidpl2.f
    f77 -c rbidpl2.f
rbdepl.o : rbdepl.f
    f77 -c rbdepl.f
rbtbcl.o : rbtbcl.f
    f77 -c rbtbcl.f
rbbd12.o : rbbd12.f
    f77 -c rbbd12.f
rbdcd.o : rbdcd.f
    f77 -c rbdcd.f
rbgfl.o : rbgfl.f
    f77 -c rbgfl.f
rbicgn.o : rbicgn.f
    f77 -c rbicgn.f
rblgda.o : rblgda.f
    f77 -c rblgda.f
rbsccl2.o : rbsccl2.f
    f77 -c rbsccl2.f
rbslrc.o : rbslrc.f
    f77 -c rbslrc.f
rbthcl2.o : rbthcl2.f
    f77 -c rbthcl2.f
```

Listing 3.1 (cont's, 5 of 6)

```
rbsc2h2.o : rbsc2h2.f
      f77 -c rbsc2h2.f
rbic2h2.o : rbic2h2.f
      f77 -c rbic2h2.f
rbscbd.o : rbscbd.f
      f77 -c rbscbd.f
rbddyn2.o : rbddyn2.f
      f77 -c rbddyn2.f
rbclfp2.o : rbclfp2.f
      f77 -c rbclfp2.f
rbduct.o : rbduct.f
      f77 -c rbduct.f
rbf2sp2.o : rbf2sp2.f
      f77 -c rbf2sp2.f
dbms.o : dbms.f
      f77 -c dbms.f
dbdpkf.o : dbdpkf.f
      f77 -c dbdpkf.f
dbslrc.o : dbslrc.f
      f77 -c dbslrc.f
dbuptb.o : dbuptb.f
      f77 -c dbuptb.f
dbdlrc.o : dbdlrc.f
      f77 -c dbdlrc.f
dbcrtb.o : dbcrtb.f
      f77 -c dbcrtb.f
dbbuke.o : dbbuke.f
      f77 -c dbbuke.f
dbc2py.o : dbc2py.f
      f77 -c dbc2py.f
dbdpda.o : dbdpda.f
      f77 -c dbdpda.f
dbgein.o : dbgein.f
      f77 -c dbgein.f
dbgeky.o : dbgeky.f
      f77 -c dbgeky.f
dbl2kf.o : dbl2kf.f
      f77 -c dbl2kf.f
dbl2tb.o : dbl2tb.f
      f77 -c dbl2tb.f
dbinld.o : dbinld.f
      f77 -c dbinld.f
dbinf2.o : dbinf2.f
      f77 -c dbinf2.f
dbpost.o : dbpost.f
      f77 -c dbpost.f
dbputg.o : dbputg.f
      f77 -c dbputg.f
```

Listing 3.1 (cont's, 6 of 6)

```
dbrddc.o : dbrddc.f
          f77 -c dbrddc.f
dbsttb.o : dbsttb.f
          f77 -c dbsttb.f
dbsvtb.o : dbsvtb.f
          f77 -c dbsvtb.f
dbswit.o : dbswit.f
          f77 -c dbswit.f
dbrdda.o : dbrdda.f
          f77 -c dbrdda.f
dbwrrc.o : dbwrrc.f
          f77 -c dbwrrc.f
dbrdfd.o : dbrdfd.f
          f77 -c dbrdfd.f
dbrdkd.o : dbrdkd.f
          f77 -c dbrdkd.f
dbwrfd.o : dbwrfd.f
          f77 -c dbwrfd.f
```

## LDEXPT OPERATIONS

The load expert system, LDEXPT version 5.0, was installed on SUN workstation.

### I. START THE LOAD EXPERT SYSTEM

- (1) Enter ldrbms52 at prompt at the directory where the executable module ldrbms52 resides
- (2) Answer queries to initialize the session:

<u>Question</u>	<u>Recommended answers</u>
(i) Is this a debug run ?	N or No
(ii) Do you wish to open an output file or a user interface file?	N for all sessions except in running the ?EXDR/SCLM module where one needs a user interface file
(iii) Please choose DATABASE display options ?	Option 0 or 2 for ?DBMS Option 5 of ?EXDR sessions

- (3) Choose a command:

?RBMS	for going to Rule Base Management System driver
?EXDR	for going to expert system consultation driver
?KBMS	for going to Knowledge Base Management System driver
?DBMS	for going to Database Management System

## II. THE LOAD EXPERT SYSTEM CONSULTATION

To run an expert system consultation session

(1) Going to the expert system consultation driver following the procedure described in operation I:

Enter ldrbms52 ...

Enter ?EXDR command to start the consultation. A list of rule modules will appear on screen:

- SLIDPL : Retrieve Independent Load Information
- SLDEPL : Retrieve Dependent Load Information
- SLICGN : Retrieve Influence Coefficients and Gains
- SLTBCL : Retrieve Turbine Blade Component Pressure Load  
Scaling Model Information
- SLTHCL : Retrieve Component Thermal Load Information
- SLSCTH : Retrieve Thermal Load Scaling Model and Influence  
Model Information
- SLICTH : Component load influence coefficients
- SLCLFP : Component fluctuation pressure load information
- SLDUCT : Duct geometry information for fluctuation pressure  
loads
- SLDDYN : Duct dynamic load PSD information
- SLDCD : Retrieve a Duty-Cycle-Data profile
- QLM : Quick Look Model for Evaluating Dependent Load
- SICM : Deterministic Influence Coefficient Model
- STBSM : Simple Scaling Model for Evaluating the Turbine  
Blade Component Pressure Load
- FPSM : Duct fluctuating pressure scaling model
- SCLM : Structural Component Life Model
- ANLDIN : Prepare ANLOAD (probabilistic load simulation) input  
file
- PSAMIN : Prepare CLSICM load module input file for PSAM or  
other applications
- EXIT : Exit the Expert System Driver

Select one of the module by entering the rule module name, e.g. QLM, the expert system will start a Quick Look Model session.

Entering SLDCD, the expert system will retrieve the requested duty cycle mission history profile data

Entering ANLDIN, the expert system will interface with the user for his/her request and prepare an input file for load simulation

III. Database Operation: Open a database file and select a database table

(1) Going to CLS database system by following procedure of operation I, choose ?DBMS

(2) A list of commands will show up on screen

<u>Command</u>	<u>Function</u>
?DBCR	Create a database
?DBCF	Create fields of a database
?DBBK	Build a database key file
?DBSL	Select database record(s)
?DBDL	Delete database record(s)
?DBDF	Display fields and key names
?DBUP	Update or add database records
?DBRD	Open a knowledge base file and read its dictionary
?DBSV	Save a database
?DBLT	List all database records
?DBLK	List key values of all database records
?DBCP	Copy a database to another knowledge base file
?INLD	Input load ID's and Properties from an engine influence model data file
?INFL	Input influence coefficient set from an engine influence model data file
?HELP	List available commands to screen
?RETN	Return to knowledge base driver (KBMS)
?QUIT	Exit the load expert system LDEXPT

(3a) If the database operation is on existing databases, the first command to execute is ?DBRD to open the database (or knowledge base) file. The command will prompt user for the database file name and the database group name (i.e. the database table name).

(3b) If one is to create a new database file or add a new database (table) to an existing database file, execute ?DBCR

(4) Once the database file is opened, other commands can be executed

#### IV. Database Operation: Select a database record

Execute the following commands:

(1) ?DBMS

(2) ?DBRD

Entering the desired database table when it is prompted  
e.g. LIDP

(3) ?DBSL

Entering the independent load ID when it is prompted.  
One needs to know what are the key fields of the database.  
If one does not have the information, go to ?EXDR to execute  
a database retrieval task where detail information is given  
at the prompt.

V. Database Operation: Add a record to an existing database or update a record

It is always a good practice to have a up-to-date backup copy of one's database file. Make a backup copy of the database file (or the knowledge base file) if it is not done before proceeding.

Execute the following commands:

(1) ?DBMS

(2) ?DBRD

(3) ?DBUP

Two options are available for this command:

(1) Add a new record

(2) Modify a record

Choose 1 (by entering 1) to add a new record to the database, DBMS will prompt for field values of the new database record.

Choose 2 for modifying an existing database record. One needs to know the record number of the database record. The record number of a record is the ordinal number of the record resided in the database group. If one does not know the record number of the database record, execute command ?DBLT. All records in the database will be listed on screen. One needs to count the records to locate the desired record. Once the record is located by ?DBUP, DBMS will prompt user for the new database field values.

(4) ?DBSV

Be sure to save the database after it is changed. Three options are available. It is recommended to use option 1: save the database under the old group and block.

### 3.2 ANLOAD

ANLOAD is implemented on SUN workstation as a stand-alone load simulation computer code.

TABLE 3.2 ANLOAD Files

<u>File Type</u>	<u>File Name</u>	<u>Description</u>
Executable	anload03	CLS ANLOAD load simulation
makefile	anload03.mak	See Listing 3.2
Input file	INFILE	ANLOAD input file
Load Reference Files	TBTPREF.DAT	HPFTP turbine blade steady state reference pressure and temperature file for the 2519 nodes FEM
	ss8.pst81	HPFTP turbine blade steady state reference temperature file for the 5000+ nodes FEM
	su6.pst81	HPFTP turbine blade start transient reference temperature file for the 5000+ nodes FEM
	co4.pst81	HPFTP turbine blade shutdown transient reference temperature file for the 5000+ nodes FEM
	HGMREF2	HGM fuel transfer duct reference temperature file
	LOXSSS	LOX post steady state reference temperature file
	LOXSYI	LOX post start transient reference temperature file
	LOXCZZ	LOX post shutdown transient reference temperature file
Utility Files	DPD.OUT	Load statistical result save file
	SCLMSAV	ANLOAD intermediate results save file

# Listing 3.2 anload03.mak

```

ANLOAD    = anloa4.o anlidi4.o phase2.o stash.o stdscp.o tmangr3.o\
            quick.o rasca4.o monte2.o trnsld.o trnspk2.o power.o\
            ritpdf.o
RASCAL    = defin2.o condm2.o combdr.o danal.o bindet.o defgau.o\
            discpd.o uzfun.o stlmt.o grpout.o endout.o nxtout.o\
            dpd.o gamma.o random.o param.o avdesc.o wrdesc.o \
            fitstd.o sort.o spike.o sample.o npoi.o nfac.o getpdf.o
CLSICM    = clsicm5.o cllddb2.o obsicm.o clmccl.o clobjs2.o\
            clhodd.o clloxp.o hgdenf.o denlox.o cltbld.o nismcc.o\
            clftrd.o clalsc.o cllscm.o clhpotpdd2.o
DATACODE  = trmval.o grtrda.o dvmean.o base.o calmom.o mcmom.o\
            dfit.o evd.o simpcm.o dismom.o
BLADE     = blxsp41.o bldyp.o
THERLD    = ther01.o ther05.o ther06.o ther15.o thenvr.o tbscth3.o\
            tdscth2.o lxscth2.o enlxpt.o gcscbd.o omccln.o\
            rdloxt2.o rdhgmd.o wrsenf.o rdtbtt.o tbrtrth.o
LIBS      = -lm -lf77
anload03 : $(ANLOAD) $(RASCAL) $(CLSICM) $(DATACODE) $(BLADE) \
            $(THERLD)
            f77 -o anload03 $(ANLOAD) $(RASCAL) $(CLSICM) $(DATACODE) \
            $(BLADE) $(THERLD) $(LIBS)
anloa4.o : anloa4.f ldcomb
            f77 -c -g anloa4.f
anlidi4.o : anlidi4.f ldcomb
            f77 -c -g anlidi4.f
phase2.o : phase2.f
            f77 -c -g phase2.f
stash.o : stash.f ldcomb
            f77 -c -g stash.f
stdscp.o : stdscp.f
            f77 -c -g stdscp.f
tmangr3.o : tmangr3.f
            f77 -c -g tmangr3.f
power.o : power.f
            f77 -c -g power.f
quick.o : quick.f ldcomb
            f77 -c -g quick.f
discpd.o : discpd.f ldcomb
            f77 -c -g discpd.f
rasca4.o : rasca4.f ldcomb
            f77 -c -g rasca4.f
monte2.o : monte2.f
            f77 -c -g monte2.f
trnsld.o : trnsld.f
            f77 -c -g trnsld.f
trnspk2.o : trnspk2.f ldcomb
            f77 -c -g trnspk2.f
ritpdf.o : ritpdf.f
            f77 -c -g ritpdf.f

```

Listing 3.2 (cont's, 2 of 4)

```
grpout.o : grpout.f
    f77 -c -g grpout.f
endout.o : endout.f
    f77 -c -g endout.f
nxtout.o : nxtout.f
    f77 -c -g nxtout.f
clsicm5.o: clsicm5.f
    f77 -c -g clsicm5.f
cllddb2.o: cllddb2.f
    f77 -c -g cllddb2.f
obsicm.o : obsicm.f
    f77 -c -g obsicm.f
clmccl.o : clmccl.f
    f77 -c -g clmccl.f
hgdenf.o : hgdenf.f
    f77 -c -g hgdenf.f
clhpotpdd2.o : clhpotpdd2.f
    f77 -c -g clhpotpdd2.f
clhodd.o : clhodd.f
    f77 -c -g clhodd.f
denlox.o : denlox.f
    f77 -c -g denlox.f
clloxp.o : clloxp.f
    f77 -c -g clloxp.f
cltbld.o : cltbld.f
    f77 -c -g cltbld.f
nismcc.o : nismcc.f
    f77 -c -g nismcc.f
clftrd.o : clftrd.f
    f77 -c -g clftrd.f
clalsc.o : clalsc.f
    f77 -c -g clalsc.f
cllscm.o : cllscm.f
    f77 -c -g cllscm.f
clobjs2.o: clobjs2.f
    f77 -c -g clobjs2.f
defin2.o : defin2.f
    f77 -c -g defin2.f
condm2.o : condm2.f
    f77 -c -g condm2.f
combdr.o : combdr.f
    f77 -c -g combdr.f
uzfun.o  : uzfun.f
    f77 -c -g uzfun.f
stlmt.o  : stlmt.f
    f77 -c -g stlmt.f
danal.o  : danal.f ldcomb
    f77 -c -g danal.f
bindet.o : bindet.f
    f77 -c -g bindet.f
```

Listing 3.2 (cont's, 3 of 4)

```
defgau.o : defgau.f
    f77 -c -g defgau.f
dpd.o    : dpd.f
    f77 -c -g dpd.f
gamma.o  : gamma.f
    f77 -c -g gamma.f
random.o : random.f
    f77 -c -g random.f
param.o  : param.f
    f77 -c -g param.f
avdesc.o : avdesc.f
    f77 -c -g avdesc.f
wrdesc.o : wrdesc.f
    f77 -c -g wrdesc.f
fitstd.o : fitstd.f
    f77 -c -g fitstd.f
sort.o   : sort.f
    f77 -c -g sort.f
spike.o  : spike.f
    f77 -c -g spike.f
sample.o : sample.f
    f77 -c -g sample.f
npoi.o   : npoi.f
    f77 -c -g npoi.f
nfac.o   : nfac.f
    f77 -c -g nfac.f
getpdf.o : getpdf.f
    f77 -c -g getpdf.f
trmval.o : trmval.f
    f77 -c -g trmval.f
grtrda.o : grtrda.f
    f77 -c -g grtrda.f
dvmean.o : dvmean.f
    f77 -c -g dvmean.f
base.o   : base.f
    f77 -c -g base.f
dfit.o   : dfit.f
    f77 -c -g dfit.f
evd.o    : evd.f
    f77 -c -g evd.f
simpcm.o : simpcm.f
    f77 -c -g simpcm.f
dismom.o : dismom.f
    f77 -c -g dismom.f
calmom.o : calmom.f
    f77 -c -g calmom.f
mcmom.o  : mcmom.f
    f77 -c -g mcmom.f
thenvr.o : thenvr.f
    f77 -c -g thenvr.f
```

Listing 3.2 (cont's, 4 of 4)

```
ther01.o : ther01.f
    f77 -c -g ther01.f
ther05.o : ther05.f
    f77 -c -g ther05.f
ther06.o : ther06.f
    f77 -c -g ther06.f
ther15.o : ther15.f
    f77 -c -g ther15.f
tbscth3.o : tbscth3.f
    f77 -c -g tbscth3.f
tbtrth.o : tbtrth.f
    f77 -c -g tbtrth.f
tdscth2.o : tdscth2.f
    f77 -c -g tdscth2.f
enlxpt.o : enlxpt.f
    f77 -c -g enlxpt.f
lxscth2.o : lxscth2.f
    f77 -c -g lxscth2.f
blxsp41.o : blxsp41.f
    f77 -c -g blxsp41.f
bldyp.o : bldyp.f
    f77 -c -g bldyp.f
gcscbd.o : gcscbd.f
    f77 -c -g gcscbd.f
omccln.o : omccln.f
    f77 -c -g omccln.f
rdloxt2.o : rdloxt2.f
    f77 -c -g rdloxt2.f
rdhgmd.o : rdhgmd.f
    f77 -c -g rdhgmd.f
rdtbtt.o : rdtbtt.f
    f77 -c -g rdtbtt.f
wrsenf.o : wrsenf.f
    f77 -c -g wrsenf.f
```

## ANLOAD OPERATION

To run anload, an input file named INFILE is required. Move INFILE to the directory where the ANLOAD executable module anload03 resides. Although ANLOAD does write OUTPUT to the computer screen, it essentially runs in a batch mode. It is recommended to record the output. The following procedure will allow one to do that:

- (1) Enter: script <logfile name>

script is a SUN OS utility program. It will records all screen output to the file name <logfile name> which is a user supplied file name.

- (2) Enter: anload03

anload03 is the executable module for the CLS load simulation module ANLOAD. It will first read input from INFILE, and then calculate the requested engine system and component loads for a time slice or a duty cycle mission profile.

ANLOAD will also write the load statistical results to a output file named DPD.OUT. If DPD.OUT does not exist, ANLOAD will create one. If it does exist, it will be overwritten with the new results.

ANLOAD also saves the intermediate results to a file named SCLMSAV as calculated by the CLS load module CLSICM every time CLSICM is called. If SCLMSAV does not exist, ANLOAD will create one. If it does exist, the old result from previous run of anload03 will be overwritten.

### 3.3 htx

htx is the CLS hypertext tutorial system.

TABLE 3.3 htx Files

<u>File Type</u>	<u>File Name</u>	<u>Description</u>
Executable	htx	CLS hypertext tutorial system
makefile	htx.mak	See Listing 3.3
Auxiliary File	clstutor	CLS hypertext tutorial material text file

#### htx OPERATION

To run a CLS tutorial session, simply enter 'htx' at the directory where htx resides. At this point, one can enter the desired "button" to start the tutorial session. If help is needed, enter 'HELP' at the prompt. The following is a list of htx commands.

<u>Command</u>	<u>Function</u>
	***** htx Commands *****
?LBTN	List the present daughter-buttons
?LBTN P	List previously shown buttons
?LBTN -1	Same as above
?LBTN P 2	List previously shown buttons two levels up
?LBTN -2	Same as above
?LBTN P n	List buttons n levels up
?LBTN -n	Same as above
?LBTN ALL	List all buttons seen thus far
	*** htx Text Commands ***
?UP n	Move card info up n lines
?DOWN n	Move card info down n lines
?TOP	Move to the beginning of the card
?END	Move to the end of the card
	These four commands can be abbreviated using only the first letter, e.g. ?U, ?D, ?T, and ?E.

Listing 3.3 htx.mak

```
HTXOBSJS = htxsys.o htcmdp.o htwcrd.o htfrd.o htwcmd.o lexho.o\  
          htlbtn.o hbpost.o clscp.o cvatoi.o iconv.o errcls.o  
htx : $(HTXOBSJS)  
      f77 -o htx $(HTXOBSJS) -lm -lF77  
htxsys.o : htxsys.f  
      f77 -c -g htxsys.f  
htcmdp.o : htcmdp.f  
      f77 -c -g htcmdp.f  
htwcrd.o : htwcrd.f  
      f77 -c -g htwcrd.f  
htfrd.o : htfrd.f  
      f77 -c -g htfrd.f  
htwcmd.o : htwcmd.f  
      f77 -c -g htwcmd.f  
lexho.o : lexho.f  
      f77 -c -g lexho.f  
htlbtn.o : htlbtn.f  
      f77 -c -g htlbtn.f  
hbpost.o : hbpost.f  
      f77 -c -g hbpost.f  
clscp.o : clscp.f  
      f77 -c -g clscp.f  
cvatoi.o : cvatoi.f  
      f77 -c -g cvatoi.f  
iconv.o : iconv.f  
      f77 -c -g iconv.f  
errcls.o : errcls.f  
      f77 -c -g errcls.f
```

### 3.4 KBIO

KBIO module is a sub-module of KBMS consists of the PROFDP module and the PUTR module. The PROFDP module creates the duty-cycle-data (DCD) mission history profile file. The PUTR module performs maintenance and update tasks of KBIO files.

TABLE 3.4 KBIO Files

<u>File Type</u>	<u>File Name</u>	<u>Description</u>
Executable	ldkbio51	CLS KBIO Utility Module
makefile	ldkbio51.mak	See Listing 3.4

# Listing 3.4 ldkbio51.mak

```

KBIO      = kbio.o dsbini2.o putblk.o gogblk.o goendf.o fixnr.o\  

           sgaddr.o putvv.o putrr.o trnfrm.o scanpf.o  

PFDP      = profdp.o addpr.o getval2.o lstprn2.o lstdat.o where.o\  

           findfl.o findgr2.o reprpf.o wrscrn.o  

DBIO      = ldexp5.o opnofl5.o opnfl.o getr.o gethdf5.o gethdg_50.o\  

           getdat.o  

LIBS      = -lm -lf77  

ldkbio51 : $(KBIO) $(DBIO) $(PFDP)  

           f77 -g -o ldkbio51 $(KBIO) $(DBIO) $(PFDP) $(LIBS)  

opnofl5.o : opnofl5.f  

           f77 -c -g opnofl5.f  

kbio.o    : kbio.f  

           f77 -c -g kbio.f  

dsbini2.o : dsbini2.f  

           f77 -c -g dsbini2.f  

ldexp5.o  : ldexp5.f  

           f77 -c -g ldexp5.f  

gethdf5.o : gethdf5.f  

           f77 -c -g gethdf5.f  

gethdg_50.o : gethdg_50.f  

           f77 -c -g gethdg_50.f  

getdat.o  : getdat.f  

           f77 -c -g getdat.f  

getr.o    : getr.f  

           f77 -c -g getr.f  

opnfl.o   : opnfl.f  

           f77 -c -g opnfl.f  

gogblk.o  : gogblk.f  

           f77 -c -g gogblk.f  

goendf.o  : goendf.f  

           f77 -c -g goendf.f  

fixnr.o   : fixnr.f  

           f77 -c -g fixnr.f  

sgaddr.o  : sgaddr.f  

           f77 -c -g sgaddr.f  

putblk.o  : putblk.f  

           f77 -c -g putblk.f  

scanpf.o  : scanpf.f  

           f77 -c -g scanpf.f  

putvv.o   : putvv.f  

           f77 -c -g putvv.f  

putrr.o   : putrr.f  

           f77 -c -g putrr.f  

trnfrm.o  : trnfrm.f  

           f77 -c -g trnfrm.f  

profdp.o  : profdp.f  

           f77 -c -g profdp.f  

findfl.o  : findfl.f  

           f77 -c -g findfl.f

```

Listing 3.4 (cont's, 2 of 2)

```
findgr2.o: findgr2.f
    f77 -c -g findgr2.f
addpr.o  : addpr.f
    f77 -c -g addpr.f
getval2.o: getval2.f
    f77 -c -g getval2.f
lstprn2.o: lstprn2.f
    f77 -c -g lstprn2.f
lstdat.o : lstdat.f
    f77 -c -g lstdat.f
reprpf.o : reprpf.f
    f77 -c -g reprpf.f
where.o  : where.f
    f77 -c -g where.f
wrscrn.o : wrscrn.f
    f77 -c -g wrscrn.f
```

## KBIO OPERATIONS

KBIO Operation: DCD profile data processing

(1) ldkbio51

(2) ?PFDP

Going to DCD profile data processing module PROFDP  
A list of PROFDP commands is shown on screen:

PROFDP AVAILABLE COMMANDS ARE :

- ?ADDF : add a new profile
- ?DLST : list profile data
- ?GETG : retrieve a profile data curve
- ?GETY : retrieve data points from a profile
- ?HELP : show a list of available commands
- ?NLST : list profile names
- ?OPNF : open an old file for processing
- \*\*\* (N/A) ?PLOT : plot a profile curve
- ?PUTR : go to ?PUTR module
- ?QUIT : exit the program (KBIO module)
- ?UPDF : update a DCD profile data
- ?RETN : return to the KBIO driver
- ?WAMI : where am I ?

The ?PLOT command is not yet available because plotting requires licensing software or Rockwell proprietary plotting package.

(3) Enter a PROFDP sub-command to continue the task.

To process existing profiles, first to open a DCD file by entering ?OPNF. The command will prompt for file name.

To create a new DCD profile data file, use the ?ADDF command.

?UPDF is used to update only the DCD data file. It can not update other KBIO file. Update of a DCD file can also be done in ?PUTR module. In fact, ?PUTR can modify any KBIO file.

## KBIO Operation: ?PUTR Module

(1) ldkbio51

(2) ?PUTR

Going to PUTR module

One can also reach ?PUTR from the PROFDP module by entering the PROFDP sub-command ?PUTR

?PUTR available commands are:

- ?OPNF : open a new or an old KBIO file
- ?GOEF : go to the end-file record
- ?GOGB : go to a group header record
- ?PUTG : write group header record
- ?PUTH : write record header
- ?PUTA : write vector data record
- ?PUTS : write scalar data record
- ?PUTV : write no more than 8 arrays
- ?ENDG : write group trailer record
- ?ENDF : write file trailer record
- ?GETG : get group header record address
- ?SCAN : scan file, a debugging tool
- ?SGAD : saving a group address
- ?FXNR : fixing the number of group regions
- ?TRNF : transform ASCII file to binary or vis versa
- ?RETN : exit the PUTR module

PUTR is the generic maintenance and debugging tool for any KBIO file. It can scan a KBIO file group-by-group and physical record-by-record. It can manually modify or repair a physical record of a KBIO file. See chapter on KBIO module for detail.

## Chapter 4. DBMS and the Knowledge Base File loadlm2

Since CLS has large volume of data and load information, and needs to perform frequent load information and data retrieval, a database management system is designed to manage the information and data. With DBMS, data maintenance is simplified, data integrity is guaranteed. Information and data in a database format can be easily coupled with an expert system query module to become an intelligent database system. Interactive tasks can then be designed and implemented on the expert system and be performed reliably so that users can avoid performing the tedious tasks of locating the required information and data.

The CLS DBMS module is a genuine database system. It uses key variables to identify and retrieve the desired data records. It can easily update and add data records to the database. It can display the data records on screen. It can change key variables. DBMS performs all commands in-core (in computer memory) except file I/O tasks. This makes it very efficient.

The available DBMS commands are:

- ?DBCR : Create a database table
- ?DBCF : Create fields for a database
- ?DBBK : Build key data
- ?DBSL : Select database record(s)
- ?DBDL : Delete database record(s)
- ?DBDF : Display field and key names
- ?DBUP : Update (Add) database record(s)
- ?DBRD : Open a database file
- ?DBSV : Save an updated database
- ?DBLT : List all of a database's records
- ?DBLK : List all key variables of a database
- ?INLD : Input load ID & properties
- ?INFL : Input influence coefficients
- ?HELP : List available database commands
- ?RETN : Return to KBMS
- ?QUIT : Exit LDEXPT

#### 4.1 DBMS Operations

The followings are some examples of DBMS operations to familiarize users with operation of the system.

##### Example (1): Open an existing database

To work with an existing database, one needs first to open the database file by entering ?DBRD. Then, one can proceed to select a database record, update a database record, etc. by entering an appropriate command, e.g. ?DBSL, the system will carry out the desired database task.

The ?INLD and ?INFL commands are not generic database functions. They are provided for the composite load spectra project to build the load knowledge base from an in-house generated influence coefficient file.

##### Example (2): Create a new database

To create a new database, one needs to run the command ?DBCR to define the database field names and their attributes. DBMS will first prompt for the number of fields of the new database table, the number of key fields, and the number of records to be entered this time. For the CLS DBMS system, the maximum number of fields for a database table is 15. The maximum number of keys is 10 and the maximum number of records for a group-block is 100. A database with a unique name (database table name or group name) can have as many group-blocks as required. DBMS will then prompt for database field-names and ask user to identify if the field is a key and its sorting order (1=primary key, 2=secondary key, etc.). After that, the system will prompt user to enter the database records.

After ?DBCR is complete, that is after ?DBCR has built the index file for the database and save the database to the database base file, one can perform other operation on the new database.

##### Example (3): Updating a database table

Modifying a database record:

- (1) Go to the CLS database system module ?DBMS
- (2) Enter ?DBRD to open the database file and retrieve the desired database. ?DBRD will prompt for the file name and the database table name (or group name).
- (3) If modification of a database record is desired, the user needs to know the record number of the record, i.e. the ordinal number of the record. If the record number is not known, one can enter ?DBLT to list all records of the database and count the order number of the desired record.
- (4) Enter ?DBUP, choose option (2), ?DBUP will prompt for the record number of the record to be modified.

- (5) ?DBUP will then prompt for the field number of the field to be modified and then the new value for the field.
- (6) After all modifications are performed, enter ?DBSV and choose option (1) to save the database file.

Adding database records:

- (1) ?DBMS
- (2) ?DBRD
- (3) Enter ?DBUP and choose option (1). ?DBUP will prompt for the number of records to be added in this session.
- (4) ?DBUP will prompt for database field values, one record at a time
- (5) When ?DBUP is complete, enter ?DBSV and choose option (1) to save the database file.

Example (4): Create rocket engine influence model databases

The CLS load expert system LDEXPT should have already the SSME influence model databases stored on the knowledge base file. The commands ?INLD and ?INFL are included for the system programmers who need to update a complete set of influence model databases or build a new set of influence model databases for a different type of rocket engines.

To build a new set of influence model databases, one needs to have an influence coefficient file following the influence coefficient file format of the Rocketdyne system performance and analysis group. The influence coefficient file essentially has three groups of data. The first group is a list of engine primitive variables or independent loads with format of (2I6,4E12.5). The data supplied for this group are:

ID, IDUM, (ANOM(j), j=1, 4)

where, ID is the independent load ID,  
IDUM is not used,  
ANOM(j)'s are the nominal value coefficient set.

The second group is a list of engine performance variables and system operating loads, or system dependent loads. The format is the same as the first group, (2I6,4E12.5). The data are:

ID, IDUM, (ANOM(j), j=1, 4)

where, ID is the dependent load ID,  
IDUM is not used,  
ANOM(j)'s are the nominal value coefficient set.

The third group is a list of engine influence coefficient set. The format is (3I4,4E12.5). The data are:

ID(i), JD(j), KDUM, (CINF(i, j, jj), jj=1, 4)

where,  $ID(i)$  is the  $i$ th independent load  
       $JD(j)$  is the  $j$ th dependent load  
      KDUM is not used  
       $CINF(i,j,jj)$ 's are the influence coefficient set

With the influence coefficient data file, one can build the engine influence model databases. The first step is to build the independent loads database. The next step is to build the dependent load database and lastly to build the influence coefficient set database. The procedure is as follows:

- (1) Run LDEXPT and go to DBMS module
- (2) Enter ?DBCF to define the fields of the independent load database
- (3) Enter ?INLD to build the database, choosing option 1 of ?INLD
- (4) When step (3) is done, choosing option 3 of ?INLD to exit from ?INLD so that the database is saved.
- (5) Exit LDEXPT and make a backup copy of the knowledge base file
- (6) Run LDEXPT and go to DBMS module
- (7) Enter ?DBCF again to define fields of the dependent load database
- (8) repeat steps (3) and (4) for dependent load database
- (9) Exit LDEXPT and make another backup copy of the knowledge base file
- (10) Enter ?DBCF to define the fields of the influence coefficient set database
- (11) Enter ?INFL to build the influence coefficient set database
- (12) Exit LDEXPT and make a back up copy of the knowledge base

## 4.2 The CLS Knowledge Base File 'loadlm2'

The CLS knowledge base file stores the load databases and load model information databases. The knowledge base file for SSME engine load models is 'loadlm2'. Databases are stored in 'loadlm2' as data group-blocks. The structures of the group-blocks are the same. Therefore, a unique set of database utility routines can be written to facilitate the database storage and retrieval. The content structure of the database group-blocks is shown below:

TABLE 4.1 The database content-structure

<u>Record No.</u>	<u>Rec.Type</u>	<u>Content</u>
1	DB attributes	NRDES(3): NFIELD,NKEY,NREC
2	Field Desc. Field name Data type Key order Col. in IDATA	KDES(30,4) KDES(ii,1),KDES(ii+1,1) KDES(ii,2) KDES(ii,3) KDES(ii,4) ii = i+i-1, i=1,NFIELD
3-22	Data	IDATA(100,j),j=1,20 IDATA(irec,l(i)), l(i)=KDES(ii,4) ii = i+i-1, i=1,NFIELD
23	Key Desc. Key name Key Data Type	KEYDES(22,2) KEYDES(ii,1),KEYDES(ii+1,1) KEYDES(ii,2) ii = i+i-1, i=1,NKEY
24-45	Key Data	KDATA(100,j),j=1,22 KDATA(irec,ii), KDATA(irec,ii+1) ii = i+i-1, i=1,NKEY

Adding a group header record to the front of the block described above and a group trailer record to the end, form a complete group-block for a database table.

## KNOWLEDGE BASE INFORMATION

DATABASE LIDP : the system independent load database

LIDP-ID : the independent load ID number  
LD-NAME : the independent load name  
MEAN : the nominal engine mean value of the load  
COV : the coefficient of variation of the load  
P3 : rare event probability, not used  
DIST : distribution type of the load  
NE-COEF1: the constant term coefficient for the nominal engine value calculation  
NE-COEF2: the first order term coefficient  
NE-COEF3: the second order term coefficient  
NE-COEF4: the third order term coefficient

The nominal engine mean value is calculated as a third order polynomial of the control power level T in power unit (i.e. T = 1 is at 100% power level):

$$\text{MEAN} = \text{COEF1} + \text{COEF2} * T + \text{COEF3} * T * T + \text{COEF4} * T * T * T$$

DATABASE LDEP : the system dependent load database

LDEP-ID : the dependent load ID number  
LD-NAME : the dependent load name  
MEAN : the nominal engine mean value  
COV : coefficient of variation  
P3 : rare event probability, not used  
DIST : distribution type of the load  
NE-COEF1: the constant term coefficient for evaluation of the load's nominal engine mean value  
NE-COEF2: the first order term coefficient  
NE-COEF3: the second order term coefficient  
NE-COEF4: the third order term coefficient

DATABASE INFC : the influence coefficient set and gains database

LDEP-ID : the dependent load ID

LIDP-ID : the independent load ID

INFL-C1 : the constant term coefficient for evaluation of the influence coefficient as a polynomial of third order control power level T in power unit

INFL-C2 : the first order term coefficient

INFL-C3 : the second order term coefficient

INFL-C4 : the third order term coefficient

GAIN65 : the gain of the dependent load at power level of 65% as a result of one sigma change in the independent load

GAIN90 : the gain at 90% power level

GAIN100 : the gain at 100% power level

GAIN104 : the gain at 104% power level

The influence coefficient is calculated the same way as the load nominal engine value:

$$IC = C1 + C2*T + C3*T*T + C4*T*T*T$$

and the percentage gain of the dependent load due to the change in the independent load is calculated as follows:

$$\begin{array}{lcl} \text{Percent change} & & \text{Percent change} \\ \text{of Dep. Load} & = & IC * \text{of Indep. Load} \end{array}$$

DATABASE LTBC : Turbine Blade Component pressure Load information

TB-C-ID : the turbine blade component ID  
TB-LD-ID: the turbine blade load ID number  
TB-LD-NA: the turbine blade load name  
LD-TYPE : load type  
LDEP1-ID: the first dependent load ID used in the scaling model  
LDEP2-ID: the second dependent load ID used in the scaling model  
          = 0 means only one dependent load is needed  
SC-COEF : the coefficient of the scaling model  
TBC-GRPN: group name of the scaling model coefficient data file

DATABASE DFAT : engine flight and test data information

DCD-ID : duty-cycle-data (engine flight or test data) ID  
LIDP-ID : the independent load ID of the data  
ENGINE : engine type  
MISSION : mission history phase  
DCD-GRPN: duty-cycle-data group name of the data file

DATABASE LCTH : the component thermal load information

CMPN-ID : the component ID number  
C-LD-ID : the component load ID number  
C-LD-NA : the component load name  
MEAN : the nominal mean value of the load  
COV : the coefficient of variation of the load  
P3 : not used  
DIST : distribution type, assumed to be normal for now  
NE-COEF1 : not used  
NE-COEF2 : not used  
NE-COEF3 : not used  
NE-COEF4 : not used

DATABASE SCTH : the thermal load scaling model and influence model database

CMFN-ID : the component ID number  
C-LD-ID : the component load ID number  
C-LD-NA : the component load name  
LD-TYPE : the load type, it is used to indicate the type of dependency of the load in its influence model  
e.g. a LD-TYPE of FOURBD means the load needs four boundary loads in its influence model calculation  
C1-ID : component ID of the first dependent load or the first boundary load  
=0 means it is a dependent load  
LDEP1-ID : the first dependent load ID or the first boundary load ID  
C2-ID : component ID of the second dependent load or the second boundary load  
LDEP2-ID : the second load ID  
C3-ID : the third component ID  
LDEP3-ID : the third load ID  
C4-ID : the fourth component ID  
LDEP4-ID : the fourth load ID  
C5-ID : the fifth component ID  
LDEP5-ID : the fifth load ID  
SC-COEF : the scaling coefficient for a LD-TYPE of ONE case  
SC-GRPN : the scaling coefficient file group name, not used

DATABASE ICTH : the boundary condition load gain database

CMFN-ID : the boundary condition load component ID  
C-LD-ID : the boundary condition load ID  
C1-ID : the dependent load component ID  
LDEP1-ID : the dependent load ID  
GAIN : the gain coefficient, used as follows

Percent change of  
the boundary load  
with C-LD-ID due = GAIN \* Percent change of  
to LDEP1 the dependent load  
LDEP1

DATABASE CLFP : the fluctuation pressure model parameters database

COMP-ID : the component ID  
C-L-ID : the component load ID  
C-L-NA : the component load name  
LOCATION : duct location where C-L-ID is to be evaluated  
DIA-EQV : equivalent diameter  
FI-RATIO : fluctuation intensity ratio  
CORLEN : correlation length  
SHAPE-F : shape factor  
FREQ-0 : lower bound of the PSD frequency range  
FREQ-I : intermediate separation point of the PSD  
FREQ-L : upper bound of the PSD frequency range  
A-L-FREQ : percentage area for the lower half of the PSD

DATABASE DUCT : duct geometry database

COMP-ID : the component ID  
C-L-ID : the component load ID  
N-ZONES : number of zones of the component  
LOC-1 : location of zone 1  
LOC-2 : location of zone 2  
LOC-3 : location of zone 3  
LOC-4 : location of zone 4  
LOC-5 : location of zone 5  
LOC-6 : location of zone 6  
LOC-7 : location of zone 7  
LOC-8 : location of zone 8  
LOC-9 : location of zone 9  
LOC-10 : location of zone 10  
LOC-11 : location of zone 11  
LOC-12 : location of zone 12

### 4.3 Programmer's Notes

#### Module : DBMS

<u>Driver</u>	<u>Commands</u>	<u>Utilities</u>	<u>KBIO</u>
DBMS -----	DBBUKE -----	DBDPDA -----	FINDFL
	DBCOPY	DBGEIN	OPNOFL
	DBCRTB	DBPUTG	ENDF
	DBDLRC	DBRDDA	ENDG
	DBDPKF	DBRDFD	GETDAT
	DBINF2	DBRDKD	GETHDF
	DBINLD	DBSTTB	GETHDG
	DBLSKF	DBWRFD	GETR
	DBLSTB	DBWRRRC	PUTA
	DBRDDC	PRPAGE	PUTB
	DBSLRC	RBLGDA	PUTG
	DBSVTB	SORKEY	PUTR
	DBUPTB		DSIREC
			DSNREC
			DSEMSG
			DBPRTR

#### 4.3.1 COMMON BLOCK /DB/

DBMS uses KBIO as its file Input/Output module. It uses the common block /DB/ to store the current database on-line (i.e. in-core memory).

```
COMMON /DB/TABLEN,NFIELD,NKEY,NREC,KDES(30,4),IDATA(100,20),  
KEYDES(22,2),KDATA(100,22)
```

where, <TABLEN> is the database table name, same as group name  
<NFIELD> is the number of fields of the database  
<NKEY> is the number of keys  
<NREC> is the number of database records  
<KDES> is the database field description array  
<IDATA> is the database data array  
<KEYDES> is the database key description array  
<KDATA> is the database key data array

The content-structure of a database table is shown in Table 4.1. In the followings, the contents of the database arrays are displayed to further illuminate the structure of the CLS databases.

Field description array KDES(30,4)

KDES(i,j)

	KDES(1,j),KDES(2,j)	KDES(3,j),KDES(4,j)	.....
j=1	Field Name No.1	Field Name No. 2	.....
j=2	DataType ---	DataType ---	.....
j=3	KeyOrder ---	KeyOrder ---	.....
j=4	ColInIDATA ---	ColInIDATA ---	.....

where DataType is the variable <KTYPE> used in the code

KTYPE = 1 for character string

= 2 integer

= 3 real

Data array IDATA(100,20)

Pointer LL(j)

where LL(j)=KDES(jj,4), jj=j+j-1

LL(j) is the pointer to the first word of the j-th field of  
a database

For example,

LL(1) = KDES(1,4) = 1

LL(2) = KDES(3,4) = 3

LL(3) = KDES(5,4) = 4

LL(4) = KDES(7,4) = 6

IDATA(i,LL(j)), i is the record (ordinal) number

Rec.	j=1 IDATA(.,1)	IDATA(.,2)	j=2 IDATA(.,3)	j=3 IDATA(.,4)	IDATA(.,5)
...					
i=1	Field Value #1		Field V #2	Field Value #3	
i=2	Field V #1 for rec.2		..	..	
i=3	Field V #1 for rec.3		..	..	
...					

Key description array KEYDES(22,2)

KEYDES(i,j)

	KEYDES(1,j)KEYDES(2,j)	KEYDES(3,j)KEYDES(4,j)	...
i=1	Key Name No. 1	Key Name No. 2	
i=2	DataType ---	DataType ---	

#### Key file array KDATA(100,22)

KDATA(i,j), i is the record (ordinal) number

For example, the first key is an integer, the second key is a character string, etc.

Rec.	KDATA(.,1)	KDATA(.,2)	KDATA(.,3)	KDATA(.,4)	...
i=1	KeyValue#1	---	Key Value	#2	
i=2	Key V. #1	---	Key Value	#2	
i=3	Key V. #2	---	Key Value	#2	
...					

#### 4.3.2. COMMON BLOCK /DBINDX/

The common block /DBINDX/ is used to stored selected record pointers for database records retrieval.

COMMON /DBINDX/NRETRV,KEY(100),INDKEY(100)

<NRETRV> is the number of records selected  
<KEY> is the key file record pointer to the record that satisfies the selection criteria  
<INDKEY> = KDATA(KEY(i),NKK), where NKK=NKEY+NKEY+1  
is the record index (pointer) that points to the record whose key file record is KEY(i). Normally, INDKEY(i) has the same value as KEY(i). Our scheme is more general. It does not require that KEY(i) and KDATA(KEY(i),NNK) has the same value. That is the order of the key file records do not have to be the same as the data records. However, the CLS DBMS code stays with the case that  
KEY(i) = KDATA(KEY(i),NNK).

#### 4.3.3 Parameter variables used in DBMS

<ISAVE> is a SAVE parameter.

<ISAVE> = 0 , the KB file has not been changed and is saved.

<ISAVE> = 1 , the KB file has been changed and not yet saved.

<IOPN> is an OPEN parameter.

<IOPN> = 0 , No KB file is open.

<IOPN> = 1 , A KB file is open.

<IDIR> is a DIRECT file parameter.

<IDIR> = 0 , the opened KB file is a sequential file.

<IDIR> = 1 , the opened KB file is a direct file.

<IDIR> = 2 , file type unknown, program will prompt user for it.

<IDISPL> is a DISPLAY parameter.

<IDISPL> = 0 , prompt user for display options

<IDISPL> = 1 , display full records, one by one

<IDISPL> = 2 , display records by lines

<IDISPL> = 3 , display field values only

<IDISPL> = 4 , display key values only

<IDISPL> = 5 , no display

<NOLDGR> is the group-block (ordinal) number.

## Chapter 5. Rule Modules and Rule Base Tools

Rule modules are routines, each of which performs a certain consultation or data retrieval tasks. Each routine is a decision tree that can interface with user using the rule base query tool. Some rule modules can also call on other modules to perform the required tasks. The query panels presented to users on screen are stored in the problem text file and retrieved with a query tool. A query panel usually consists of knowledge about a database and an associated query. The query panels are activated by "tokens". Most the time a token for a database is associated with a key field-name of the database.

The rule module tasks consist of the following categories: (1) retrieval of load information and data; (2) engine system and component load model simulations; and (3) preparation of an input file for a mission load simulation. The available rule modules are:

for load information retrieval

- SLIDPL : Independent load information
- SLDEPL : Dependent load information
- SLICGN : Influence coefficient set and gain values
- SLTBCL : Turbine blade component pressure load information
- SLTHCL : Component load information
- SLSCTH : Component thermal load influence model information
- SLICTH : Component load influence coefficients
- SLCLEP : Component fluctuation pressure load information
- SLDUCT : Duct geometry information for fluctuation pressure loads
- SLDDYN : Duct dynamic load PSD information
- SLDCD : Duty-cycle-data profiles information

for engine system and load simulation

- QLM : Quick-Look Model, Gaussian probabilistic engine system load simulation
- SICM : Deterministic engine system influence model load simulation
- STBSM : Simple turbine blade scaling model
- FPSM : Duct fluctuation pressure scaling model
- SCLM : Structural Component Life Model

for preparation of mission load simulation input file

- ANLDIN : Preparing ANLOAD (probabilistic load simulation module) input file
- PSAMIN : Prepare CLS embedded load module (CLSICM) input file for PSAM or other applications

### 5.1 Load Information Retrieval Rule Modules

The CLS expert system's tool box has a genuine database management system which greatly facilitate information and data retrieval and storage. The function and available tools of the database management system is presented in a separate session. In general, the database system will take care of the generic database functions such as load model information and data storage and retrieval, information display, update and maintenance.

The CLS expert system couples the database system with the expert system query tool and its text knowledge file (the CLS problem text file) to transpose it into an intelligent database system. The expert system uses the field-names of a database as "buttons" to retrieve the text information and queries from the text file, display them on the computer CRT screen and receive user' response. Fig. 5.1 shows an example of the coupling of queries to database SCLM, the structural component life model database used to generate load information and load values for a component life prediction evaluation.

The CLS expert system also has a mechanism to automate the data retrieval process. It can use information from a database to retrieve information from another database. This is accomplished by storing the key information obtained from the first database in a work memory and using the information of the work memory to retrieve information from a second database. The automatic database retrieval process is an integral part of the expert system rule modules. The CLS rule modules seem to show knowledge of the engine load models and know what and where to obtain the required database because of the automatic database retrieval mechanism.

The database load information retrieval rule modules listed on the previous page serve as stand-alone database retrieval process modules for respective databases. They can also be called by other modules to supply information from their databases.

# Figure 5.1 CLS INTELLIGENT DATABASE

## ● DATABASE SCLM

CMPN-ID	6	Please select a component ID 1 HPFT 5 HGM Fuel Center Transfer Tube 6 LOX Post ...
CMPN-LOC	THREAD	
C-LD-ID	45	
C-LD-NA	LPTHRLCF	Which is the location of the COMPONENT that you want to analyze ?  Please enter the key word: THREAD, IN-WELD  THREAD : Threaded location  IN-WELD : Inertia Weld location
LD-TYPE	TEN	
LDEP1-ID	48	
LDEP2-ID	29	What is the FAILURE MODE that you want to consider ? 45 LCF (Low Cycle Fatigue) Damage 46 HCF (High Cycle Fatigue) Damage
LDEP3-ID	72	
LDEP4-ID	20	
LDEP5-ID	15	
LDEP6-ID	9	
LDEP7-ID	16	
LDEP8-ID	6031	
LDEP9-ID	6030	
LDEPA-ID	6036	

## 5.2 Engine System and Load Simulation Modules

### The Quick Look Model Rule Module QLM

The quick look model is implemented on the engine influence model to obtain the load values of engine system dependent variables. The probabilistic load values are calculated using the Gaussian algebra assuming all random variables are normally distributed. Therefore, it is called the Quick Look Model.

The QLM rule module first queries the user to select a engine system dependent variable from the available 99 variables listed on screen. The variables are listed using the load names. The load names and their descriptions are delineated in Table 5.1. QLM is then call in rule module RBIDPL to retrieve the engine system primitive variables (or independent variables). Their load names and descriptions are delineated in Table 5.2. The selection of primitive variables can be done manually or by the expert system. The expert system selects the most influential primitive variables based on the gain information stored in the database. Once again, the system shows sign of intelligence in knowing how to select variables.

With the load information available so far, QLM automatically retrieves the necessary influence coefficients and then finishes the dependent load value calculation using the Gaussian algebraic formula written in the routine. It then prints the results on the computer screen. The Quick Look Model gives users a quick look at the system dependent load values and their variations.

### The Deterministic Engine Influence Model Rule Module SICM

This rule module is similar to QLM module, using engine influence model to evaluate the engine system dependent load values, except that it is doing a deterministic point value calculation. It prompts user for the values of the primitive variables and then calculates the dependent load value using the influence model.

### The Simple Turbine Blade Scaling Model Rule Module STBSM

The HPFTP turbine second stage blade loads: the centrifugal force (or equivalently turbine speed) and the cross section average tangential and axial pressures are evaluated using the simple turbine blade scaling model. The model assumes that the turbine blade correlated system dependent variables are independent and all random variables including the turbine blade loads are normally distributed. The rule module was first implemented to test the methodology and codes. It is no longer considered to be very useful.

TABLE 5.1 DEPENDENT LOAD ID's and LOAD NAMES

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
1	ENG-THRU	Engine altitude thrust (LBF)
2	HPOTP-SP	High Pressure Oxidizer Turbopump speed (RPM)
3	HPFTP-SP	High Pressure Fuel Turbopump speed (RPM)
4	HPOP-PO	High Pressure Oxidizer Turbopump discharge pressure (PSIA)
5	PBP-PO	Preburner Booster Pump discharge pressure (PSIA)
6	HPFP-PO	High Pressure Fuel Turbopump discharge pressure (PSIA)
7	OPB-CB-P	Oxidizer Preburner Chamber pressure (PSIA)
8	FPB-CB-P	Fuel Preburner Chamber pressure (PSIA)
9	ENG-O-FL	Engine oxidizer flowrate (LBM/SEC)
10	ENG-F-FL	Engine fuel flowrate (LBM/SEC)
11	O-PRS-FL	Oxidizer pressurant flowrate (LBM/SEC)
12	F-PRE-FL	Fuel pressurant flowrate (LBM/SEC)
13	OPB-O-VP	Oxidizer Preburner oxidizer valve position (%)
14	FPB-O-VP	Fuel Preburner oxidizer valve position (%)
15	MCC-O-IP	Main Combustion Chamber oxidizer injector pressure (PSIA)
16	MCCHG-IP	Main Combustion Chamber hot gas injector pressure (PSIA)
17	MCC-IEP	Main Combustion Chamber injector end pressure (PSIA)
18	HPOP-PI	High Pressure Oxidizer Turbopump inlet pressure (PSIA)
19	HPFP-PI	High Pressure Fuel Turbopump inlet pressure (PSIA)
20	HPOP-TO	High Pressure Oxidizer Turbopump discharge temperature (degree R)
21	HPFP-TO	High Pressure Fuel Turbopump discharge temperature (degree R)
22	MFV-TO	Main Fuel Valve discharge temperature (degree R)
23	PBP-TO	Preburner Booster Pump discharge temperature (degree R)
24	HPOP-TI	High Pressure Oxidizer Turbopump inlet temperature (degree R)
25	HPFP-TI	High Pressure Fuel Turbopump inlet temperature (degree R)
26	LPOTP-SP	Low Pressure Oxidizer Turbopump speed (RPM)
27	LPFTP-SP	Low Pressure Fuel Turbopump speed (RPM)
28	HPOT-TO	High Pressure Oxidizer Turbopump Turbine discharge temperature (degree R)

TABLE 5.1 (cont's)

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
29	HFTTD-TO	High Pressure Fuel Turbopump Turbine Transfer Duct discharge temperature (degree R)
30	OPB-OV-R	Oxidizer Preburner Oxidizer Valve resistance
31	FPB-OV-R	Fuel Preburner Oxidizer Valve resistance
32	O-PRS-P	Oxidizer pressurant pressure (PSIA)
33	F-PRS-P	Fuel pressurant pressure (PSIA)
34	O-PRS-T	Oxidizer pressurant temperature (degree R)
35	LPFT-TO	Low Pressure Fuel Turbopump Turbine discharge temperature (degree R)
36	LPOP-NSS	Low Pressure Oxidizer Turbopump suction specific speed (NSS)
37	LPFP-NSS	Low Pressure Fuel Turbopump suction specific speed (NSS)
38	HPOP-NSS	High Pressure Oxidizer Turbopump suction specific speed (NSS)
39	HPFP-NSS	High Pressure Fuel Turbopump suction specific speed (NSS)
40	MCC-C-PO	Main Combustion Chamber coolant discharge pressure (PSIA)
41	LPOT-TQ	Low Pressure Oxidizer Turbopump Turbine torque (FT-LBF)
42	LPFT-TQ	Low Pressure Fuel Turbopump Turbine torque (FT-LBF)
43	HPOT-TQ	High Pressure Oxidizer Turbopump Turbine torque (FT-LBF)
44	HPFT-TQ	High Pressure Fuel Turbopump Turbine torque (FT-LBF)
45	LPOT-FL	Low Pressure Oxidizer Turbopump Turbine flowrate (LBM/S)
46	LPFT-FL	Low Pressure Fuel Turbopump Turbine flowrate (LBM/S)
47	HPOT-FL	High Pressure Oxidizer Turbopump Turbine flowrate (LBM/S)
48	HPFT-FL	High Pressure Fuel Turbopump Turbine flowrate (LBM/S)
49	LPOT-PI	Low Pressure Oxidizer Turbopump Turbine inlet pressure (PSIA)
50	LPFT-PI	Low Pressure Fuel Turbopump Turbine inlet pressure (PSIA)
51	HPOT-PI	High Pressure Oxidizer Turbopump Turbine inlet pressure (PSIA)
52	HPFT-PI	High Pressure Fuel Turbopump Turbine inlet pressure (PSIA)
53	LPOT-TI	Low Pressure Oxidizer Turbopump Turbine inlet temperature (degree R)
54	LPFT-TI	Low Pressure Fuel Turbopump Turbine inlet temperature (degree R)

TABLE 5.1 (cont's)

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
55	HPOT-TI	High Pressure Oxidizer Turbopump Turbine inlet temperature (degree R)
56	HPFT-TI	High Pressure Fuel Turbopump Turbine inlet temperature (degree R)
57	LPOT-PO	Low Pressure Oxidizer Turbopump Turbine discharge pressure (PSIA)
58	LPFT-PO	Low Pressure Fuel Turbopump Turbine discharge pressure (PSIA)
59	HPOT-PO	High Pressure Oxidizer Turbopump Turbine discharge pressure (PSIA)
60	HPFT-PO	High Pressure Fuel Turbopump discharge pressure (PSIA)
61	LPOT-PW	Low Pressure Oxidizer Turbopump Turbine power (BHP)
62	LPFT-PW	Low Pressure Fuel Turbopump Turbine power (BHP)
63	HPOT-PW	High Pressure Oxidizer Turbopump Turbine Power (BHP)
64	HPFT-PW	High Pressure Fuel Turbopump Turbine power (BHP)
65	HGM-F-PI	Hot Gas Manifold fuel side inlet pressure (PSIA)
66	HGM-O-PI	Hot Gas Manifold oxidizer inlet pressure (PSIA)
67	O-TD-DP	Oxidizer Transfer Duct dynamic pressure (PSIA)
68	O-TD-FLV	Oxidizer Transfer Duct flow velocity (FT/S)
69	F-TD-DP	Fuel Transfer Duct dynamic pressure (PSIA)
70	F-TD-FLV	Fuel Transfer Duct flow velocity (FT/S)
71	HPOT-MR	High Pressure Oxidizer Turbopump Turbine mixture ratio (O/F)
72	HPFT-MR	High Pressure Fuel Turbopump Turbine mixture ratio (O/F)
73	OPB-PW	Oxidizer Preburner power (BHP)
74	FPB-PW	Fuel Preburner power (BHP)
75	MCC-PW	Main Combustion Chamber power (BHP)
76	OPB-OM-P	Oxidizer Preburner oxidizer in manifold pressure (PSIA)
77	OPB-FM-P	Oxidizer Preburner fuel in manifold pressure (PSIA)
78	FPB-OM-P	Fuel Preburner oxidizer in manifold pressure (PSIA)
79	FPB-FM-P	Fuel Preburner fuel in manifold pressure (PSIA)
80	PBP-O-TO	Preburner Booster Pump discharge, Preburner oxidizer supply temperature (degree R)

TABLE 5.1 (cont's)

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
81	MIX-F-TO	Mixer discharge, Preburner fuel supply temperature (degree R)
82	F-HGM-VL	Fuel Hot Gas Manifold velocity (FT/S)
83	F-HGM-DP	Fuel Hot Gas Manifold dynamic pressure (PSIA)
84	LXHGM-VL	LOX Hot Gas Manifold velocity (FT/S)
85	LXHGM-DP	LOX Hot Gas Manifold dynamic pressure (PSIA)
86	OPB-F-DP	Oxidizer Preburner fuel dynamic pressure (PSIA)
87	OPB-F-FV	Oxidizer Preburner fuel flow velocity (FT/S)
88	FPB-F-DP	Fuel Preburner fuel dynamic pressure (PSIA)
89	FPB-F-FV	Fuel Preburner fuel flow velocity (FT/S)
90	HPOP-DPO	High Pressure Oxidizer Turbopump discharge dynamic pressure (PSIA)
91	HPOP-VO	High Pressure Oxidizer Turbopump discharge velocity (FT/S)
92	HPOP-HR	High Pressure Oxidizer Turbopump head rise (FT)
93	HPFP-DPO	High Pressure Fuel Turbopump discharge dynamic pressure (PSIA)
94	HPFP-VO	High Pressure Fuel Turbopump discharge velocity (FT/S)
95	HPFP-HR	High Pressure Fuel Turbopump head rise (FT)
96	PBP-DPO	Preburner Booster Pump discharge dynamic pressure (PSIA)
97	PBP-VO	Preburner Booster Pump discharge velocity (FT/S)
98	HGM-C-PI	Hot Gas Manifold coolant inlet pressure (PSIA)
99	ENG-N-VO	Engine Nozzle exit velocity (FT/S)

TABLE 5.2 INDEPENDENT LOAD ID's AND LOAD NAMES

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
1	MR	Commanded mixture ratio (O/F)
2	F-PI	Fuel inlet total pressure (PSIA)
3	O-PI	Oxidizer inlet total pressure (PSIA)
4	F-TI	Fuel inlet temperature (degree R)
5	O-TI	Oxidizer inlet temperature (degree R)
6	F-PRS-FL	Fuel pressurant flowrate (LBM/S)
7	O-PRS-FL	Oxidizer pressurant flowrate (LBM/S)
8	HPFP-CAV	High Pressure Fuel Turbopump cavitation (%)
9	LPFP-CAV	Low Pressure Fuel Turbopump cavitation (%)
10	LPOP-CAV	Low Pressure Oxidizer Turbopump cavitation (%)
11	NOZM-DLP	Nozzle, Mixer delta pressure (%)
12	MCC-TH-D	Main Combustion Chamber throat diameter (IN)
13	NOZ-EX-D	Nozzle exit diameter (IN)
14	LPFT-NA	Low Pressure Fuel Turbopump Turbine nozzle area (IN <sup>2</sup> )
15	LPOT-NA	Low Pressure Oxidizer Turbopump Turbine nozzle area (IN <sup>2</sup> )
16	LPFP-EM	Low Pressure Fuel Turbopump efficiency multiplier (%)
17	HPFP-EM	High Pressure Fuel Turbopump efficiency multiplier (%)
18	LPFT-EM	Low Pressure Fuel Turbopump Turbine efficiency multiplier (%)
19	HPFT-EM	High Pressure Fuel Turbopump Turbine efficiency multiplier (%)
20	LPOP-EM	Low Pressure Oxidizer Turbopump efficiency multiplier (%)
21	HPOP-EM	High Pressure Oxidizer Turbopump efficiency multiplier (%)
22	PBP-EM	Preburner Booster Pump efficiency multiplier (%)
23	LPOT-EM	Low Pressure Oxidizer Turbopump Turbine efficiency multiplier (%)
24	HPOT-EM	High Pressure Oxidizer Turbopump Turbine efficiency multiplier (%)
25	HPOP-CAV	High Pressure Oxidizer Turbopump cavitation (%)
26	LPFP-HC	Low Pressure Fuel Turbopump head coefficient (%)
27	HPFP-HC	High Pressure Fuel Turbopump head coefficient (%)
28	LPOP-HC	Low Pressure Oxidizer Turbopump head coefficient (%)
29	PBP-HC	Preburner Booster Pump head coefficient (%)

TABLE 5.2 (cont's)

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
30	MCC-OD-R	Main Combustion Chamber Oxidizer Dome resistance
31	HGM-O-R	Hot Gas Manifold oxidizer side resistance
32	HGM-F-R	Hot Gas Manifold fuel side resistance
33	MCC-HGIR	Main Combustion Chamber Hot Gas Injector resistance
34	HGM-CO-R	Hot Gas Manifold coolant oxidizer side resistance
35	LPOPDD-R	Low Pressure Oxidizer Turbopump Discharge Duct resistance
36	P-FAP-R	Primary Faceplate resistance
37	S-FAP-R	Secondary Faceplate resistance
38	LPFT-SR	Low Pressure Fuel Turbopump Turbine Seal resistance
39	HPOT-CCR	High Pressure Oxidizer Turbopump Turbine Coolant Circuit resistance
40	HPFPDD-R	High Pressure Fuel Turbopump Discharge Duct resistance
41	MFV-R	Main Fuel Valve resistance
42	MOV-R	Main Oxidizer Valve resistance
43	MCC-O-IR	Main Combustion Chamber Oxidizer Injector resistance
44	MCC-CJDP	Main Combustion Chamber Cooling Jacket delta pressure
45	OPB-F-IR	Oxidizer Preburner Fuel Injector resistance
46	FPB-F-IR	Fuel Preburner Fuel Injector resistance
47	LPFTDD-R	Low Pressure Fuel Turbopump Turbine Discharge Duct resistance
48	LPFT-IDR	Low Pressure Fuel Turbopump Turbine Inlet Duct and F-7 resistance
49	PBP-IDR	Preburner Booster Pump Inlet Duct resistance
50	CCV-R	Coolant Control Valve resistance
51	BAF-FL-C	Baffle flow coefficient
52	PB-FSD-R	Preburner Fuel Supply Duct resistance
53	NOZ-DLP	Nozzle delta pressure (%)
54	HPOT-EBR	High Pressure Oxidizer Turbopump Turbine End Bearing coolant resistance
55	MCC-CSTR	Main Combustion Chamber combustion efficiency (MCC CSTAR)
56	NOZ-HL	Nozzle heat load (%)
57	MCC-HL	Main Combustion Chamber heat load (%)
58	HPFT-FLC	High Pressure Fuel Turbopump Turbine flow coefficient
59	HPOT-FLC	High Pressure Oxidizer Turbopump Turbine flow coefficient

TABLE 5.2 (cont's)

<u>LOAD ID</u>	<u>LOAD NAME</u>	<u>LOAD DESCRIPTION</u>
60	PB-CB-EM	Preburner combustion efficiency multiplier (%)
61	MXR-DLP	Mixer delta pressure (%)
62	LOX-FLC	LOX flow constant (C2)
63	MCC-PCER	Main Combustion Chamber PC measurement error (%)
64	ENG-FFLE	Engine Fuel Flowmeter error (%)

### The Duct Fluctuating Pressure Scaling Model Rule Module FPSM

This rule module generates a fluctuating pressure PSD, a fluctuating pressure autocorrelation function and its correlation length at certain location of a duct. The user needs to indicate the location of interest of the duct to the code. Detail modeling of the fluctuating pressure scaling model is presented in the section of the component load model. This generic fluctuating pressure scaling model is appropriate for many ducts. The one important parameter of the model is the fluctuation intensity factor. Its value can be obtained from experimental data or estimation by an expert. Advanced physical model of the duct fluctuating pressures has been developed, user needs to consult the appropriate section in this report.

### The Structural Component Life Model Rule Module SCLM

The structural component life model rule module SCLM was implemented to supply a list of component loads and engine variables with their load values to be used in a component life prediction evaluation. The approach taken is that for the rule module to generate a file containing the variable ID list and the variable load values. The file is then used as an input file in the component life prediction calculation. The file format is preset and agrees with the requirement of the life calculation code.

The list of component loads includes the component internal loads, component environment variables or boundary loads (such as turbine blade hot gas temperature, etc.) and component local variables (such as hot gas heat transfer film coefficient factor, etc.). The component loads are required for a structural component life prediction calculation and is known to the component life prediction analyst. The list of the component loads is stored in database SCLM. Algorithms to compute the component load values are implemented as component load object functions. These load object functions are coupled to the engine system model (see section on component load model for detail). The algorithms employed are in general the scaling technique and the influence model. The advantage of using the load object functions is that all the model constants and coefficients and the model calculation method are encapsulated in the object function. The disadvantage is that the object function can only be used for one SCLM component. Section 5.1 of the main report (Ref. 7) details an implementation of the LOX post SCLM model. The available SCLM models are the LOX post threaded region low cycle fatigue (LCF) and high cycle fatigue (HCF) SCLM models, the HPOTP discharge duct pressure fluctuation load SCLM model, and the MCC (main combustion chamber) liner SCLM model.

### 5.3 Load Simulation Input File Preparation Modules

#### The ANLOAD Input File Preparation Rule Module ANLDIN

The rule module ANLDIN is used to prepare input files for the CLS load simulation module ANLOAD. This is a widely used expert system rule module because the main function of the CLS code is to perform probabilistic component load simulation of a space propulsion system. ANLDIN has to be able to prepare load simulation input file for all component loads that are implemented in the CLS coupled multi-level engine model. A file named INFILE is generated at the end of each ANLDIN session that can be used as an ANLOAD input file. The ANLOAD input file user's guide defining the input variables is attached as Appendix I.

The component loads implemented in the load simulation module engine load model include the HPFTP turbine blade centrifugal force (or turbine speed), cross sectional average tangential and axial pressures, turbine blade finite element model (2519 nodes FEM) steady-state nodal pressures and temperatures, turbine blade 5000+ nodes FEM steady-state and transient temperatures, HGM fuel transfer duct static pressures, HGM oxidizer transfer duct static pressures, main injector LOX post static pressures and HPOTP discharge duct static pressure, HGM fuel transfer duct thermal load (temperatures), LOX post steady-state and transient thermal load, MCC liner thermal load, and ALS chamber liner thermal load. An ANLOAD input file for any one and some combination of the loads listed above can be generated with ANLDIN.

The load simulation can be a single point calculation or a mission duty-cycle-data (DCD) profile simulation. For DCD load simulation, there are a few set of duty-cycle-data profiles stored and available in the DCD file named "SSMEdcd" (see section on KBIO module). There are 5 power profile options available. During the DCD query, a user can select one of the available power profile options as listed in Table 5.3. IPWR=2 option is for a SSME flight/test simulation. The power profile will be retrieved from the DCD file for the flight/test.

TABLE 5.3 ANLOAD power file options

DCD-query	IPWR	POWER PROFILE
CONS	0	constant
CONS	1	constant ramp
PWRPTS	3	specified (time, power) points
PWRMAN	4	manual power profile input
PWRDCD*	2	SSME flight or test power profile (* user selects one of the available flight or test ID's)

For the IPWR=1 constant ramp option, the power level PL is given by the following equation:

$$PL = PWR0 + PWRATE * (TIME - TIME0)$$

where,

PWR0 is the power level at time  $t = TIME0$ , the beginning time

PWRATE is the constant ramp rate of the power profile

TIME is the time at which the loads are simulated

For the IPWR=3 option, specific (time, power) pairs are entered. The load simulation will be evaluated only at those times with the corresponding power levels.

For the IPWR=4 option, a linear piecewised power profile assumed by entering the the beginning and end points and the discrete points where the profile changes its slope.

This module will also prompt users for a few of the modeling parameters and options, and the DCD mission phase time intervals. Users should consult the ANLOAD input file user's manual for the definitions of the parameters and variables. The DCD mission phase time intervals are required input for every engine system dependent variables in a DCD load simulation. Be sure that the time intervals are consistent. It is recommended that the same mission phase time intervals are used for all system dependent variables.

There are three probabilistic methods: GAUSSIAN ALGEBRA, RASCAL and Monte Carlo, are available for use in the probabilistic load simulation. The GAUSSIAN ALGEBRA method (input file parameter MODEL=1) is implemented for engine system influence model only. That is one can use it to calculate the engine system dependent loads only. It is generally not recommended. The RASCAL method (MODEL=2) and the Monte Carlo method (MODEL=3) are good for all loads modeled by the CLS coupled multi-level engine model.

#### The PSAM Load Module Input File Preparation Rule Module PSAMIN

A subset of the CLS deterministic load model module is copied and embedded in a Rocketdyne PSAM probabilistic structural analysis software system that is used for component structural analysis and life prediction calculation. The PSAMIN rule module prepares an input file containing all load database information that are required for the embedded load module to evaluate the component load values. PSAMIN uses the SCLM database. Therefore, it can only prepare input file for those loads that are in the SCLM database. The SCLM rule module also prepares an input file for a component life prediction code. The difference between the SCLM and the PSAMIN rule modules is that the component load values are calculated by SCLM and recorded in the input file, whereas no calculation is done by PSAMIN. The input file from PSAMIN is used by the PSAM system to calculate the loads.

## 5.4 Programmer's Notes

### Routines of the CLS Rule Based Management System (RBMS) Module

<u>Driver</u>	<u>--- Rule Modules ---</u>	<u>Utilities</u>
RBMS	RBIDPL	QUERY
SESUIM	RBDEPL	RBACCS
RBDRIV	RBICGN	GRSPRC
	RBTBCL	SLSCLM
	RBTHCL	CLOBSJS
	RBSCTH	INPREP
	RBICTH	DSBINI
	RBCLEP	
	RBDUCT	
	RBDDYN	
	RBDCD	
	RBQLM	
	RBSICM	
	RBSSM	
	RBFPSP	
	RBSCLM	
	RBTBIN	
	RBPSAM	

To run the CLS load expert system LDEXPT, enter the executable module name: "ldrbms52" together with the correct path to the directory where ldrbms52 is resided. The following is an example of running the ANLDIN rule module:

- (1) Enter: ldrbms52      /\* Execute the LDEXPT code
- (2) Enter: ?EXDR        /\* going to the expert system  
                         /\* a panel of available rule  
                         /\* modules are listed on screen
- (3) Enter: ANLDIN        /\* running the rule module that  
                         /\* prepare a load simulation  
                         /\* input file

Most of these routines will prompt users for the name of the file where all databases are stored. The file name for the CLS databases is "loadlm2".

The query panel is the database prompt that shows up on screen during an expert system consultation session. The query panels are stored in the CLS problem text file named "LDKBPTE". It is an ASCII text file that can be easily edited. An associated rule file named "LDKBRUL" of the problem text file is used to provide text information for the code to record the operations of the consultation ses-

sion on a file named "LOGFIL". The LOGFIL can also be used to debug or check the correctness of the operations.

The files: loadlm2, LDKBPTF, and LDKBRUL, should be in the same directory as the executable module "ldrbms52". The logical units of these files are defined in initialization routine DSBINI. The logical unit for the database file "loadlm2" is NDBS=14. The logical unit for "LDKBPTF" is NPTF=12. The logical unit for "LDKBRUL" is NRLF=10. The logical unit for "LOGFIL" is NLGF=8.

An option parameter IOPT is used in all database retrieval routines such as RBIDPL, and RBICGN, etc., with the following meaning:

IOPT = 0, Manually select the database records by prompting the users to select the key values  
IOPT = 1, Automatically select the database records based on the information in working memory

## Chapter 6. KNOWLEDGE BASE INPUT/OUTPUT MODULE KBIO

KBIO is the Knowledge Base Input/Output module. Its main function is to retrieve a database from the knowledge base file into in-core memory, and to save a database to the knowledge base file when it is created or updated. Both the DBMS and PROFDP modules use the I/O routines of KBIO to process the files.

The knowledge base file where the databases are stored is a direct access file so that updating of the databases is possible. The KBIO routines were originally written for sequential file operation. Although the routines were adopted to run direct access files, most the operations are still in a sequential file mode. In the next version of LDEXPT, modification will be made to the routines to operate more in tune with the direct access mode.

The KBIO module is designed to perform of the file Input/Output tasks, speed up the I/O and take care of the formatting problem so that there is a universal format for all files using the KBIO system. The CLS knowledge base file is a KBIO file. It follows the KBIO format detailed in this chapter. The group-block data unit is a database table.

## 6.1 DUTY-CYCLE-DATA (DCD) MISSION PROFILE PROCESSING MODULE PROFDP

The DCD mission profile data processing module PROFDP is a utility module for generating the duty-cycle-data which is used in a mission history simulation load evaluation. Its function is to store (to a file) and retrieve engine mission data in a piecewise linear form. The module uses the KBIO routines to generate a DCD file storing a few of typical SSME flight and test duty-cycle-data profiles. The DCD file 'SSMEDcd' contains the power level profiles, the mixture ratio profiles, the fuel inlet pressure profiles, the oxidizer inlet pressure profiles, the fuel inlet temperature profiles and the oxidizer inlet temperature profiles for the following flight and tests :

DATA	ID	Mission time
flight	STS61-A	500 sec
test	902-384	250 sec
test	902-387	500 sec
test	750-262	250 sec
test	901-495	250 sec
test	901-491	500 sec

The DCD profile data are stored by group names. The group names are build into the DFAT database. When a user requests a set of DCD profile data, the expert system will obtain the group names from the DFAT database and then retrieve the profiles with the group names. The group names are listed in Table 6.1. The DFAT database has the following field structure:

<u>DB-field</u>	<u>Example</u>	<u>Description</u>
DCD-ID	STS61-A	DCD flight/test ID
LIDP-ID	0	Primitive variable ID for power
ENGINE	SSME	Engine type
MISSION	FLIGHT	Mission type
DCD-GRPN	PWR1	DCD data group name

TABLE 6.1 DCD Profile Data Group Names

<u>Group Name</u>	<u>Data-ID</u>	<u>Description</u>
PWR1	STS61-A	power level profile
MXR1	STS61-A	mixture ratio profile
PIF1	STS61-A	fuel inlet pressure (PSIA)
PIO1	STS61-A	oxidizer inlet pressure (PSIA)
TIF1	STS61-A	fuel inlet temperature (R)
TIO1	STS61-A	oxidizer inlet temperature (R)
FLF1	STS61-A	fuel inlet flowrate (lbm/sec)
FLO1	STS61-A	oxidizer inlet flowrate (lbm/s)
PWR3	902-384	power level profile
MXR3	902-384	mixture ratio profile
PIF3	902-384	fuel inlet pressure (PSIA)
PIO3	902-384	oxidizer inlet pressure (PSIA)
TIF3	902-384	fuel inlet temperature (R)
TIO3	902-384	oxidizer inlet temperature (R)
PWR4	902-387	power level profile
MXR4	902-387	mixture ratio profile
PIF4	902-387	fuel inlet pressure (PSIA)
PIO4	902-387	oxidizer inlet pressure (PSIA)
TIF4	902-387	fuel inlet temperature (R)
TIO4	902-387	oxidizer inlet temperature (R)
PWR5	750-262	power level profile
MXR5	750-262	mixture ratio profile
PIF5	750-262	fuel inlet pressure (PSIA)
PIO5	750-262	oxidizer inlet pressure (PSIA)
TIF5	750-262	fuel inlet temperature (R)
TIO5	750-262	oxidizer inlet temperature (R)
PWR6	901-495	power level profile
MXR6	901-495	mixture ratio profile
PIF6	901-495	fuel inlet pressure (PSIA)
PIO6	901-495	oxidizer inlet pressure (PSIA)
TIF6	901-495	fuel inlet temperature (R)
TIO6	901-495	oxidizer inlet temperature (R)
PWR7	901-491	power level profile
MXR7	901-491	mixture ratio profile
PIF7	901-491	fuel inlet pressure (PSIA)
PIO7	901-491	oxidizer inlet pressure (PSIA)
TIF7	901-491	fuel inlet temperature (R)
TIO7	901-491	oxidizer inlet temperature (R)

The PROFDP module can create a duty-cycle-data file, add DCD profile data, and retrieve the DCD profile data curves. It also has debugging tool for the programmer to repair corrupted DCD file and change profile data. The commands are listed below.

<u>PROFDP COMMAND</u>	<u>COMMAND FUNCTION</u>
?ADDF	create/add a new DCD profile curve
?DLST	list DCD profile data
?GETG	retrieve a DCD profile
?HELP	list available commands of PROFDP
?NLST	list DCD profile group names
?OPNF	open an existing file for processing
?PUTR	a utility module inc. a debugging tool
?QUIT	exit the program
?RETN	return to MAIN
?UPDF	updating a DCD profile
?WAMI	where am I ?

At this time the PROFDP module together with the utility module PUTR are implemented as an independent program 'ldkbio51' on a Rocketdyne SUN workstation. To run the computer program, one simply enters 'ldkbio51'. The process is interactive and the program will prompt for information.

As stated earlier, each DCD profile data curve is stored as a group-block of data under a group name in the DCD file. Each group-block of data consists of a title record, a x-axis title record, a y-axis title record and three records of data, one for the values of x, one for y and one for the coefficients of variation of y. For this application, x is always the time variable, y is the duty-cycle-data profile variable. The following is a example of the content of a group-block for group name TI05.

<u>RECORD No.</u>	<u>REC.TYPE</u>	<u>CONTENT</u>
1	Title	750-262 Test
2	X-title	Mission time
3	Y-title	Oxidizer inlet temperature (R)
4	X (7-points)	0.0,8.0,250.0,254.0,262.0,269.0, 295.0
5	Y	173.0,164.5,164.5,170.0,170.0, 185.5,176.5
6	Stand.dev.	0.01,0.01,0.01,0.01,0.01,0.01, 0.01

The actual data block of course has more information which includes the group name, record indexes and the length of each record. This additional information allows the code to recognize and retrieve the desired information. The module provides a command ?UPDF for updating the DCD profile data. If the titles are to be modified, or a few of the data points are to be changed, ?UPDF command will prompt for the desired item and read in the changes. If many data points are to be changed, or more data points are to be added,

?UPDF is not very convenient or will not work. In this situation, the ?SCAN command of the PUTR module should be used. It is advisable to make a backup copy of the DCD file before proceeding to use the ?SCAN command to modify the DCD file. In PUTR module, there is a command ?TRNF which will transform the binary DCD file into an ASCII file or vis versa. It should be very helpful to users who wish to study and modify the DCD file.

## 6.2 PROGRAMMER'S NOTES

### Module KBIO

<u>Driver</u>	<u>Modules</u>	<u>Commands</u>	<u>Utilities</u>
KBIO	PROFDP	FINDFL	GETDAT
		FINDGR	GETHDG
		ADDP	GETR
		REPRPF	WRSCRN
		GETVAL	PUTA
		LSTPRN	PUTG
		LSTDAT	PUTF
		WHERE	PUTR
	PUTBLK	OPNFL	OPNOFL
		PUTRR	GETHDF
		PUTGG	GETRSC
		PUTAA	WRIREC
		PUTSS	ERRCHK
		PUTVV	PUTB
		ENDG	PUTV
		ENDF	DSNREC
		GGOBLK	DSIREC
		GOENDF	DSEMSG
		SGADDR	DSPRTR
		FIXNR	
		SCANPF	
		TRNFRM	

Executable module ---- ldkbio51  
DCD file for SSME ---- SSME dcd

### KBIO file constructs

Record structure (for all records)

<name> NN INDEX LEN Data...

#### file header record

The first record of the KBIO file

<name> is the filename <FLNAME>

NN = 1

INDEX = -9000

LEN = length of data = 8

Data = LABF(5) = default maximum logical data block length = 51

LABF(10) = address of end-file block

LABF(11) = old group name = <NAMOLD> for internal usage

### end-file block

The last block of data of any KBIO file is an end-file block. The end-file block stored the group names of all data group-block and the group-block address-index table for use by the ISAM data retrieval scheme.

1st record of end-file block

<name> = <FLNAME>

NN = -1

INDEX = -9000

LEN = 8

Data = Repeat of the file header record data

2nd record of end-file block

<name> = <FLNAME>

NN = 0

INDEX = -9000

LEN = 1

Data = number of records in the address-index table

This is of course also the number of distinct groups in the file

= <NGRP>

3rd to <NGRP+2> records of end-file block

<name> = group name of a data group-block = <IDGRP(1,.)>

NN = 0

INDEX = -7000

LEN = <IDGRP(3,.)+2>

In general it is 3

If the group has several separate contiguous blocks of data, then LEN will increase by the number of contiguous blocks minus 1

= 3

Data = <IDGRP(2,.)>, <IDGRP(3,.)>, <IDGRP(4,.) ...>

<IDGRP(2,.)> is the number of group-blocks with the group name. Beware that there can be many group-blocks with the same group name. This number is different from the contiguous blocks. If all these group-blocks are physically contiguous in the KBIO file, then the number for the contiguous blocks is 1.

<IDGRP(3,.)> is the number of physically contiguous blocks.

<IDGRP(4,.)> is the address-index of the group of the first contiguous block. If there are more address-indices that need to be saved, the code would store them in <IDGRP(5,.)>, <IDGRP(6,.)> and so on. One trick for the programmers. If the group has a large number of data blocks, even though they are physically contiguous, one can still save a few address-indices of group-blocks in equal spacing. This will speed up the data retrieval of those groups.

#### last record of end-file block

This is also the last record of the KBIO file

<name> = '\*EOF'  
NN = 0  
INDEX = 0  
LEN = 1  
Data = 0.0

#### DATA GROUP-BLOCK

This is the data block for storing information and data.

#### 1st record of a group-block

This is a group header record.

<name> = group name for the data block  
NN = the ordinal number of the group-block  
INDEX = -7000  
LEN = 8  
Data = The 8 words can be used for passwords such that users have to give the correct passwords in order to access the data in the block. CLS does not use them and set them to zero.

#### 2nd record of a group-block

This is the first data block of this group-block.

<name> = group name  
NN = the ordinal number of data blocks in this group-block  
= 1  
INDEX = same as the NN in the group header record  
LEN = length of the data in number of words (4-byte word)  
Data

Each data record can only contain 51 words of data (<LABF(5)> = 51, default set in the code). Therefore the number of physical records (actual records in the file for this group-blocks) is dependent on the length of data.

Each logical record includes the record that has the group name and the INDEX information, follows if required by as many records as needed for data.

Each group-block of data can have any number of logical records. The programmer who generates the KBIO file knows how many logical records are there in his/her file and should write a retrieval routine specific for the file. Of course, if one chooses to use the CLS DCD file format, then all the generation and retrieval routines are already available.

last record of the group-block

This is a group trailer record. After all data are stored, one needs the group trailer record to end the group-block.

<name> = group name

NN = negative of the ordinal number of group-blocks with the same group name

= -1 (means it is the group trailer record of the first group-block of <name>. In CLS, most group has distinct name except for the INFC database)

INDEX = -7000

LEN = 1

Data = the number of logical records of this group-block.

## Chapter 7. CLS Hypertext Tutorial System

The CLS tutorial system was implemented to provide on-line tutorials to the user community on the CLS load simulation system. The goal of this task is to implement a working version of the tutorial system and not worry about having sufficient tutorial materials at this time. The tutorial system was implemented using a simple version of the hypertext technology, no advanced artificial intelligence techniques such as building a "student" model (trying to guess a user's intention and difficulties) are explored.

Information and text knowledge are stored in card format. The cards are retrieved with key words. Physically, the text materials are stored in a text file which can be edited and updated with a text editor. This makes building the "cards" a simple task. However, this means that the text file is a sequential file which could slow down the "card" retrieval operation. If it turns out that the system is too slow, the compiled knowledge technique can be used to translate the knowledge into binary direct file to speedup the operation. The CLS's KBIO module with its indexing I/O scheme can be employed for this purpose.

The organization of the tutorial information will be an important issue. An ideal organization will require minimal storage and avoid information redundancy. Semantic nets consisting of nodes and links have been developed by early AI (Artificial Intelligence) researchers as a knowledge representation tool. Knowledge represented by nodes can be associated or inferred through the links. In the CLS hypertext tutorial system, the semantic network scheme is used to provide a knowledge representation (Fig. 7.1) and a framework to organize the CLS information into a hierarchical network of semantic nets. It should facilitate the construction of the tutorial files. However, the semantic net representation is only used here to help organize the CLS tutorial materials. Mechanism has not been implemented for reasoning with semantic networks, that is providing understanding of the meaning of the semantic nets.

### 7.1 Implementation of the hypertext system

The system consists of a "card" information management system, a key-board command lexical analyzer, a command processor and a tutorial text file. The card information management system carries out the information retrieval based on the requested button and display of the card information to the screen. The lexical analyzer analyzes a user input and send it to the command processor and the command processor carries out the command requested. The lexical analyzer and command processor could be expanded and implemented for the expert system driver so that the system can go from a module to another module without going through all those panels of

Figure 7.1 CLS HYPERTEXT Knowledge Representation

- USING HYPERTEXT TECHNOLOGY

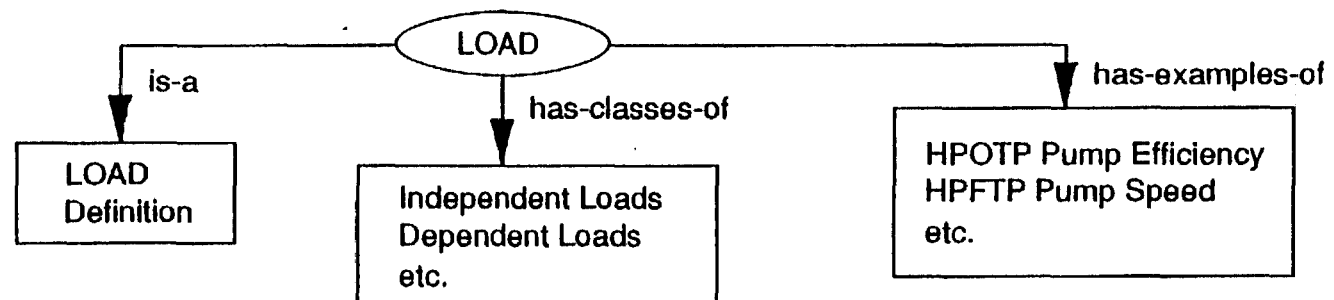
STORING INFO IN INDEX CARD FORMAT

RETRIEVAL OF TEXT WITH KEY WORDS

- USING SEMANTIC NET

TO ORGANIZE INFORMATION

EXAMPLE :



menu that are shown on the screen as it is being done on the present system.

The tutorial text file is deigned to contain "cards". Each card has a button (key-word) serves as an index for information retrieval and a number of lines of text. The number of lines can be more than a screenful. The hypertext displaying routine will display the card information one screen at a time and wait for user command to continue. At the end of the card, a list of daughter-buttons are displayed. One of them can be selected by typing in the button to continue the chain of information. Other buttons can also be selected to branch off to a different chain of information. Fig. 7.2 shows the card as shown on screen when the button "CLS" is entered. Fig. 7.2a shows the button input. Fig. 7.2b is the "CLS" card. At the bottom of the card, a daughter-button "CLS-ENGN" is listed. In this case there is only one daughter-button. For other cards, there could be more daughter-buttons.

The hypertext system has two command sets. The first command set is for moving the card information up and down a number of lines, and moving to the top or bottom of the card file. The second command set is to list the available buttons. It can list the present daughter-buttons, the previously shown buttons or all buttons seen thus far. The following is a list of the hypertext commands.

<u>Command</u>	<u>Function</u>
?LBTN	List the present daughter-buttons
?LBTN P	List previously shown buttons
?LBTN -1	Same as above
?LBTN P 2	List previously shown buttons two levels up
?LBTN -2	Same as above
?LBTN P n	List buttons n levels up
?LBTN -n	Same as above
?LBTN ALL	List all buttons seen thus far
?UP n	Move card info up n lines
?DOWN n	Move card info down n lines
?TOP	Move to the beginning of the card
?END	Move to the end of the card
	These four commands can be abbreviated using only the first letter, e.g. ?U, ?D, ?T, and ?E.

```

***** HTX COMMAND PROCESSOR *****
Please enter Hypertext Button or Command:---?---
CLS

```

(a) htx Input Panel

```

*****
CLS
CLS stands for Composite Load Spectra.
The CLS computer program is a probabilistic load
simulation system that can synthesize component
loads of a space propulsion system :CLS-ENGN:
(rocket engines).

The CLS code has a knowledge base that includes
a large volume of engine load information and data.
It is built as an expert system so that it can
interface with users to perform consultation tasks.

::CLS-ENGN::
*****

```

(b) htx Card: "CLS" Card Information

Figure 7.2 CLS Hypertext System htx Display Screens

## 7.2 PROGRAMMER'S NOTES

<u>Driver</u>	--	<u>Cmd Processors</u>	--	<u>Commands</u>	--	<u>Utilities</u>
htxsys		htcmdp		htwcrd		htfrd
		lexho		htwcmd		hbpost
				htlbtn		clscp
						cvatoi
						iconv
						errcls

The tutorial materials are stored in the file 'clstutor'. The format of the tutorial material file is very similar to the CLS expert system problem text file. The rules are as follows:

(1) Each button or key-word is following a line containing a left square bracket '[' in the first column. Each button occupies a line starting from the first column. Buttons or key-words are limited to 8 characters.

(2) A daughter button is a button which appears in the card of text of her parent-button. A button (line) is followed by a line filled with her daughter-buttons. The daughter-button line starts with a double-colon and ends with a double-colon, with daughter-buttons in between. The daughter-buttons are separated with double-colons. Only double-colon can be next to a double-colon.

(3) Card text is following the daughter-button line. Each line of card text begins with a question mark '?'. Each line should be no longer than 80 columns including the question mark. A blank line needs also to start with a question mark.

## Chapter 8. CLS Load Module CLSICM

The CLS load module CLSICM is an independent module where all engine and component load models are implemented. As described in chapter 1 and shown in Fig. 1.4, the CLS load module is a multi-level coupled engine model which is composed of a rocket engine influence model coupled with many component load models. The architecture of the coupled engine model is presented in chapter 1 of this manual. In this chapter, the engine and load models are documented as much as possible. The values of various parameters used in the load models such as scaling coefficients are also presented as a record for reference.

### 8.1 Engine System Influence Model

The Composite Load Spectra approach to the probabilistic load development is to synthesize loads with information extracted from engine data and the detail analysis results of the deterministic engine and load models. The CLS probabilistic load models treat the engine operation as a stochastic process. The engine hardware parameters, operating inlet condition variables and all engine loads are assumed to be random variables.

The influence coefficient model developed for engine performance evaluation is ideal for CLS. It is a numerical abstract of the engine model. It can evaluate engine loads for different power levels. With the random variable assumption, the probabilistic methods can be applied to the influence coefficient model to obtain the load distributions. This probabilistic influence model thus becomes the CLS system level engine model. It provides all the system operation condition loads subsequently used by the component load model to generate component loads.

The engine influence model utilizes the influence coefficients to correlate the changes in the engine operating parameters and inlet condition variables, classified as system primitive variables or independent loads, to the changes in the system operation conditions and system performance variables, classified as system dependent loads. The influence equation is

$$\frac{\Delta Y_i}{Y_{io}} = \sum_j (IC)_{ij} \frac{\Delta X_j}{X_{jo}} \quad (8.1)$$

where,

$X_{jo}$  is the nominal value of the  $j$ th engine independent load

$\Delta X_j = (X_j - X_{jo})$  is the change in the  $j$ th independent load

$Y_{io}$  is the nominal value of the  $i$ th dependent load

$\Delta Y_i = (Y_i - Y_{i0})$  is the change in the  $i$ th dependent load  
 $(IC)_{ij}$  is the influence coefficient correlating the  $j$ th independent load to the  $i$ th dependent load

The nominal values for the independent loads (with a few exceptions) are not varied with the commanded power level. The nominal values for the dependent loads and the influence coefficients are functions of power level. Their variations are fitted into a polynomial function of the commanded power level as below:

$$Y_{i0} = a_0 + a_1*T + a_2*T*T + a_3*T*T*T$$

$$(IC)_{ij} = c_0 + c_1*T + c_2*T*T + c_3*T*T*T \quad (8.2)$$

where,

$a_i$ 's and  $c_i$ 's are constant coefficients,

$T$  is the commanded power level in fraction of the rated power.

The engine influence model implemented on the load expert system has 64 system primitive variables listed in Table 1.1 and 99 system dependent loads as listed in Table 1.2. The distribution information of the independent loads is obtained based on 10 second average database of the SSME flight and test data. These load parameters are stored in the load expert system knowledge base in database format. They can be conveniently retrieved and updated. The deterministic influence model is valid for the power range from 65% to 110% power levels. In CLS, the power range of the probabilistic influence model is extended down to zero. The complete duty cycle of the engine operation is therefore modeled by the same influence model. During the transient phase of the duty cycle, quasi-steady state is assumed. That is, the loads behave as steady state loads within each time step. Discussion on the duty cycle load calculation and transient model is deferred to next section.

## 8.2 COMPONENT LOAD SCALING MODELS

The component load is a local load such as the component temperature local to the component of interest such as turbine blade and LOX post. Component loads are normally sensitive to the geometry of the component. The component load scaling models presented here are linear scaling models directly coupled to the engine system variables. Once the engine system variables are identified these scaling models are very simple and easy to implement.

### HPFT Turbine Blade Component Pressure Loads

The turbine blade pressure loads are evaluated in CLS using linear scaling law. The tangential pressure load is scaled with the turbine torque and the axial pressure load is with the differential pressure across the cross section of the blade which includes the evaluated node. The scaling coefficients of the pressure load models are summarized in Tables 8.1-8.7. Each load model is described in detail as follows:

(1) The Turbine Blade Centrifugal Load (rpm)

The component ID is ITBCOM=1 and the component load ID is IBLOAD=1

The turbine blade centrifugal load as used here is a synonym of the turbine speed (rpm). The turbine speed is one of the dependent loads can be calculated with the influence model. Therefore, for the turbine blade centrifugal load the scaling coefficient is 1.0.

(2) The Blade Mid-Point Stage 1 Tangential Load (lbf/blade)

ITBCOM=1 & IBLOAD=2

The blade mid-point tangential load is the tangential force per blade (lbf/blade) acted on by the working fluid. The tangential load is scaled with the turbine torque which is a dependent load of the influence model. The scaling coefficient is obtained for the 100% (RPL) power level condition of which the blade mid-point stage 1 tangential load is 190 lbf/blade and the HPFT turbine torque is 9378 ft-lbf. The scaling equation is therefore,

$$F_{t1} = 2.026e-2 * \text{Torque}$$

- (3) The Blade Mid-Point Stage 2 Tangential Load (lbf/blade)  
ITBCOM=1 & IBLAOD=3

It is the same as component load number 2 except this is for stage 2 rotor blade. The scaling load is the HPFT stage 2 turbine torque. The scaling coefficient is obtained for the RPL condition of which the blade mid-point stage 2 tangential load is 180 lbf/blade and the HPFT turbine torque is 9378 ft-lbf. The scaling equation is

$$F_{t2} = 1.1919e-2 * \text{Torque}$$

- (4) The Blade Mid-Point Stage 1 Axial Load (lbf/blade)  
ITBCOM=1 & IBLOAD=4

The blade mid-point axial load is the axial force per blade acted on by the working fluid. The load is scaled with the pressure drop across the turbine, i.e. the pressure difference between the turbine inlet and the turbine outlet. The turbine inlet pressure and the outlet pressure are assumed strongly correlated in this scaling model. The scaling coefficient is obtained for the RPL condition of which the turbine mid-point axial force is 140 lbf/blade and the pressure drop is 1423 psia.

$$F_{a1} = 9.8384e-2 * (P_{inlet} - P_{outlet})$$

- (5) The Blade Mid-Point Stage 2 Axial Load (lbf/blade)  
ITBCOM=1 & IBLOAD=5

It is the same as the component load number 4 but for stage 2 rotor. The scaling coefficient is obtained for the RPL condition of which the turbine mid-point axial force is 112 lbf/blade and the pressure drop across the turbine is 1423 psia.

$$F_{a2} = 7.8707e-2 * (P_{inlet} - P_{outlet})$$

- (6) The Blade Dist. Stage 1 Tip Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=6

The blade distributed tip tangential load is the tangential force acted on the tip section of the turbine blade (lbf/section) which is divided into 7 equal cross sections. The scaling is the same as the component load number 2.

$$F_{t1,tip} = 2.8303e-3 * \text{torque}$$

(7) The Blade Dist. Stage 2 Tip Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=7

It is the same as component load number 5 above.

$$F_{t2,tip} = 1.6651e-3 * torque$$

(8) The Blade Distributed Stage 1 Tip Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=8

The blade distribution tip axial load is the axial force acted on the tip section of the turbine blade. The scaling is the same as the component load number 4.

$$F_{a1,tip} = 1.9024e-2 * (P_{inlet} - P_{outlet})$$

(9) The Blade Distributed Stage 2 Tip Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=9

It is the same as component load number 7 above.

$$F_{a2,tip} = 1.522e-2 * (P_{inlet} - P_{outlet})$$

(10) The Blade Dist. Stage 1 Mean Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=10

The blade distributed mean tangential load is the tangential force acted on the mean section of the turbine blade.

$$F_{t1,m} = 2.8899e-3 * Torque$$

(11) The Blade Dist. Stage 2 Mean Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=11

$$F_{t2,m} = 1.7002e-3 * Torque$$

(12) The Blade Distributed Stage 1 Mean Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=12

$$F_{a1,m} = 1.4225e-2 * (P_{inlet} - P_{outlet})$$

(13) The Blade Distributed Stage 2 Mean Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=13

$$F_{a2,m} = 1.138e-2 * (P_{inlet} - P_{outlet})$$

(14) The Blade Dist. Stage 1 Hub Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=14

The blade distributed hub tangential load is the tangential force acted on the hub section of the turbine blade.

$$F_{t1,hub} = 2.9654e-3 * \text{Torque}$$

(15) The Blade Dist. Stage 2 Hub Tangential Load (lbf/section)  
ITBCOM=1 & IBLOAD=15

$$F_{t2,hub} = 1.7446e-3 * \text{Torque}$$

(16) The Blade Distributed Stage 1 Hub Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=16

$$F_{a1,hub} = 8.833e-3 * (P_{inlet} - P_{outlet})$$

(17) The Blade Distributed Stage 2 Hub Axial Load (lbf/section)  
ITBCOM=1 & IBLOAD=17

$$F_{a2,hub} = 7.0664e-3 * (P_{inlet} - P_{outlet})$$

The scaling coefficients for the component loads 1-17 are listed in Table 8.1.

(18) The Blade Stage 1 Tip X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=18

The blade cross section pressure at a particular node on the circumference of the cross section can be evaluated as the sum of the cross section average pressure and the differential pressure between the pressure at the node and the average cross section pressure. In the scaling model, the cross section average pressure is scaled with the turbine inlet pressure. For the blade stage 1 tip cross-section average pressure the scaling coefficient is obtained at the RPL condition of which the average pressure is 5116.499 psia and the turbine inlet pressure is 5916 psia. The differential pressure term is scaled by the turbine torque which is at the RPL condition 10829.156 ft-lbf.

$$P_{node} = 0.8649 * P_{inlet} + SC_{node} * P_{diff}.$$

The differential pressures and the corresponding scaling coefficients are listed in Table 8.2. There is a total of 33 nodes selected.

(19) The Blade Stage 2 Tip X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=19

The load is the same as the component load number 18 above. The differential pressures and the scaling coefficients are listed in Table 8.5.

$$P_{node} = 0.6645 * P_{inlet} + SC_{node} * P_{diff}.$$

(20) The Blade Stage 1 Mean X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=20

It is the same kind of load for the mean cross-section as the component load number 18. The scaling model is the same. The differential pressures and the scaling coefficients are listed in Table 8.3.

$$P_{node} = 0.8565 * P_{inlet} + SC_{node} * P_{diff}.$$

(21) The Blade Stage 2 Mean X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=21

The pressures and the scaling coefficients are listed in Table 8.6.

$$P_{node} = 0.6645 * P_{inlet} + SC_{node} * P_{diff}.$$

(22) The Blade Stage 1 Hub X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=22

The pressures and the scaling coefficients are listed in Table 8.4.

$$P_{node} = 0.8488 * P_{inlet} + SC_{node} * P_{diff}.$$

(23) The Blade Stage 2 Hub X-section Pressure Distribution  
ITBCOM=1 & IBLOAD=23

The pressures and the Scaling coefficients are listed in Table 8.7.

$$P_{node} = 0.6631 * P_{inlet} + SC_{node} * P_{diff}.$$

TABLE 8.1 TURBINE BLADE PRESSURE LOAD DATABASE

LOAD	Scaling Coefficient
Blade centrifugal load (rpm)	1.0
Blade mid-point stage 1	
tangential load (lbf/blade)	2.0260E-2
Blade mid-point stage 2	
tangential load (lbf/blade)	1.1919E-2
Blade mid-point stage 1	
axial load (lbf/blade)	9.8384E-2
Blade mid-point stage 2	
axial load (lbf/blade)	7.8707E-2
Blade distributed stage 1	
tip tangential load (lbf/section)	2.8303E-3
Blade distributed stage 2	
tip tangential load (lbf/section)	1.6651E-3
Blade distributed stage 1	
tip axial load (lbf/section)	1.9024E-2
Blade distributed stage 2	
tip axial load (lbf/section)	1.5220E-2
Blade distributed stage 1	
mean tangential load (lbf/section)	2.8899E-3
Blade distributed stage 2	
mean tangential load (lbf/section)	1.7002E-3
Blade distributed stage 1	
mean axial load (lbf/section)	1.4225E-2
Blade distributed stage 2	
mean axial load (lbf/section)	1.1380E-2
Blade distributed stage 1	
hub tangential load (lbf/section)	2.9654E-3
Blade distributed stage 2	
hub tangential load (lbf/section)	1.7446E-3
Blade distributed stage 1	
hub axial load (lbf/section)	8.8330E-3
Blade distributed stage 2	
hub axial load (lbf/section)	7.0664E-3

TABLE 8.2 TURBINE BLADE CROSS SECTION PRESSURE LOAD DATABASE  
HPFT STAGE 1 ROTOR TIP CROSS SECTION

Average pressure 5116.499  
Inlet pressure 5916  
Radius 5.537  
Scaling coefficient for the average pressure 0.8649  
  
Number of nodes 33

X-coordinate	Differential pressure	Scaling coef.
0.135213	205.5769	1.8984E-2
0.211524	39.83496	3.6785E-3
0.264941	-49.0350	-4.5281E-3
0.318315	-129.949	-1.2000E-2
0.369154	-203.979	-1.8836E-2
0.421957	-271.982	-2.5116E-2
0.475862	-358.848	-3.3137E-2
0.523585	-411.093	-3.7962E-2
0.570578	-421.592	-3.8931E-2
0.611717	-366.630	-3.3856E-2
0.650739	-289.854	-2.6766E-2
0.693277	-307.450	-2.8391E-2
0.728947	-347.136	-3.2056E-2
0.769396	-528.892	-4.8840E-2
0.749265	-48.1580	-4.4471E-3
0.703885	32.00596	2.9555E-3
0.657621	91.25796	8.4271E-3
0.604314	160.2399	1.4797E-2
0.555132	205.4799	1.8975E-2
0.509027	235.8959	2.1783E-2
0.467476	255.5109	2.3595E-2
0.427462	268.2109	2.4767E-2
0.394480	273.1709	2.5226E-2
0.359035	272.0879	2.5125E-2
0.3246	269.0459	2.4845E-2
0.288710	258.0039	2.3825E-2
0.249288	253.8159	2.3438E-2
0.206498	226.6509	2.0930E-2
0.178267	185.0129	1.7085E-2
0.160279	96.94496	8.9522E-3
0.147289	8.035969	7.4207E-4
0.133721	114.0349	1.0530E-2
0.123297	283.7799	2.6205E-2

TABLE 8.3 TURBINE BLADE CROSS SECTION PRESSURE LOADS DATABASE  
HPFP STAGE 1 ROTOR MEAN PRESSURES

Average pressure (psia) 5066.961  
Inlet pressure (psia) 5916  
Radius (in) 5.095  
Scaling coefficient for the average pressure 0.8565

Number of nodes 35

X-coordinate (in)	Differential pressure (psia)	Scaling coef.
0.061552	196.2012	1.8118E-2
0.075181	135.0372	1.2470E-2
0.110205	65.4462	6.0435E-3
0.159677	-15.7078	-1.4505E-3
0.217097	-96.6758	-8.9274E-3
0.274396	-142.939	-1.3199E-2
0.334210	-198.069	-1.8290E-2
0.339972	-249.095	-2.3002E-2
0.460762	-299.244	-2.7633E-2
0.517578	-349.486	-3.2273E-2
0.571305	-369.059	-3.4080E-2
0.615117	-394.813	-3.6458E-2
0.661390	-272.756	-2.5187E-2
0.704076	-260.855	-2.4088E-2
0.743417	-286.712	-2.6476E-2
0.783124	-416.684	-3.8478E-2
0.762997	-62.1478	-5.7389E-3
0.713147	-14.7188	-1.3592E-3
0.657314	38.5202	3.5571E-3
0.601453	99.6932	9.2060E-3
0.543640	150.9032	1.3935E-2
0.492825	190.3772	1.7580E-2
0.447533	213.1222	1.9680E-2
0.405270	222.0542	2.0505E-2
0.364505	229.0382	2.1150E-2
0.332189	235.2272	2.1722E-2
0.294454	228.3982	2.1091E-2
0.25173	227.4032	2.0999E-2
0.210048	212.5502	1.9628E-2
0.160928	193.5572	1.7874E-2
0.118843	151.9192	1.4029E-2
0.098418	26.4982	2.4469E-3
0.087894	52.0362	4.8052E-3
0.064684	294.4452	2.7190E-2
0.058820	266.5432	2.4613E-2

TABLE 8.4 TURBINE BLADE CROSS SECTION PRESSURE LOAD DATABASE  
HPFT STAGE 1 ROTOR HUB CROSS SECTION

Average pressure (psia) 5021.622  
Inlet pressure (psia) 5916  
Radius (in) 4.653  
Scaling coefficient for the average pressure 0.8488

Number of node 36

X-coordinate (in)	Differential pressure (psia)	Scaling Coef.
0.001953	44.02991	4.0659E-3
0.010953	-15.6120	-1.4417E-3
0.049712	-26.5870	-2.4551E-3
0.111698	-100.828	-9.3108E-3
0.174543	-134.133	-1.2386E-2
0.240290	-154.390	-1.4257E-2
0.306032	-172.652	-1.5943E-2
0.375255	-207.788	-1.9188E-2
0.440999	-222.047	-2.0966E-2
0.499914	-257.460	-2.3775E-2
0.55973	-260.906	-2.4093E-2
0.607672	-227.736	-2.1030E-2
0.662385	-163.456	-1.5094E-2
0.705520	-162.343	-1.4991E-2
0.718353	-191.949	-1.7725E-2
0.754572	-173.052	-1.5980E-2
0.718353	-191.949	-1.7725E-2
0.706497	-161.320	-1.4897E-2
0.658021	-13.8830	-1.2820E-3
0.596112	34.41391	3.1779E-3
0.53514	97.70491	9.0224E-3
0.475233	132.0839	1.2197E-2
0.422215	157.6589	1.4559E-2
0.377063	175.4539	1.6202E-2
0.335366	185.3549	1.7116E-2
0.293206	186.2629	1.7200E-2
0.253006	187.2209	1.7289E-2
0.209845	195.0879	1.8015E-2
0.163284	191.8909	1.7720E-2
0.112351	175.6089	1.6216E-2
0.066361	145.4829	1.3434E-2
0.043015	83.00991	7.6654E-3
0.030679	110.6329	1.0216E-2
0.015050	256.9219	2.3725E-2
0.004662	288.5859	2.6649E-2
0.001015	195.6869	1.8070E-2

TABLE 8.5 TURBINE BLADE CROSS SECTION PRESSURE LOAD DATABASE  
HPFT STAGE 2 ROTOR TIP CROSS SECTION

Average pressure (psia) 3915.945  
Inlet pressure (psia) 5916  
Radius (in) 5.587  
Scaling coefficient for the average pressure 0.6645

Number of nodes 40

X-coordinate (in)	Differential pressure (psia)	Scaling coef.
0.114561	313.7754	2.8975E-2
0.131305	203.0914	1.8754E-2
0.151365	78.1574	7.2173E-3
0.163040	7.0484	6.5087E-4
0.203980	39.2214	3.6218E-3
0.248891	-42.9636	-3.9674E-3
0.294302	-124.151	-1.1465E-2
0.340136	-213.440	-1.9720E-2
0.384566	-294.599	-2.7204E-2
0.429960	-377.809	-3.4888E-2
0.471833	-472.037	-4.3589E-2
0.517604	-508.752	-4.6980E-2
0.562343	-431.196	-3.9818E-2
0.606258	-334.407	-3.0880E-2
0.650841	-276.055	-2.5492E-2
0.690429	-169.031	-1.5609E-2
0.708706	-151.364	-1.3977E-2
0.727448	-136.745	-1.2627E-2
0.751025	-130.353	-1.2037E-2
0.783414	-125.229	-1.1564E-2
0.750152	-117.185	-1.0821E-2
0.734596	-101.568	-9.3791E-3
0.724878	-91.1766	-8.4195E-3
0.695750	-56.9666	-5.2605E-3
0.674045	-13.8746	-1.2812E-3
0.648454	33.3754	3.0820E-3
0.605020	116.5274	1.0761E-2
0.561430	180.4764	1.6666E-2
0.514794	231.3704	2.1366E-2
0.476862	267.8574	2.4735E-2
0.428061	293.5404	2.7106E-2
0.384094	310.9944	2.8718E-2
0.340036	317.3294	2.9303E-2
0.292973	315.6654	2.9150E-2

TABLE 8.5 (cont's)

0.248743	300.7754	2.7775E-2
0.203270	253.5704	2.3416E-2
0.188250	214.5784	1.9815E-2
0.161756	150.6454	1.3911E-2
0.139350	228.1324	2.1066E-2
0.114062	312.7794	2.8883E-2

TABLE 8.6 TURBINE BLADE CROSS SECTION PRESSURE LOAD DATABASE  
HPFT STAGE 2 ROTOR MEAN CROSS SECTION

Average pressure (psia) 3931.031  
Inlet pressure (psia) 5916  
Radius (in) 5.095  
Scaling coefficient for the average pressure 0.6645

Number of nodes 34

X-coordinate (in)	Differential pressure (psia)	Scaling coef.
0.062114	262.4139	2.4232E-2
0.087547	143.0809	1.3213E-2
0.114936	28.81191	2.6606E-3
0.164823	47.15191	4.3542E-3
0.227915	-51.8480	-4.7878E-3
0.267042	-97.2820	-8.9833E-3
0.31693	-158.877	-1.4671E-2
0.365349	-218.453	-2.0173E-2
0.416215	-264.868	-2.4459E-2
0.465613	-325.453	-3.0053E-2
0.515989	-346.574	-3.2004E-2
0.565387	-328.235	-3.0310E-2
0.615274	-286.623	-2.6468E-2
0.664672	-235.904	-2.1784E-2
0.715048	-204.409	-1.8876E-2
0.770805	-151.651	-1.4004E-2
0.815801	-91.8380	-8.4806E-3
0.771294	-83.8560	-7.7435E-3
0.752219	-77.8340	-7.1874E-3
0.715538	-57.6900	-5.3283E-3
0.664183	2.889911	2.6686E-4
0.615274	57.40491	5.3010E-3
0.564409	116.9739	1.0802E-2
0.516478	162.3859	1.4995E-2
0.465613	198.6819	1.8347E-2
0.414747	218.7899	2.0204E-2
0.365349	232.8299	2.1500E-2
0.31693	243.8369	2.2517E-2
0.267042	242.6989	2.2412E-2
0.213243	230.4189	2.1278E-2
0.162866	200.9479	1.8556E-2
0.114447	109.7579	1.0135E-2
0.062114	246.2239	2.2737E-2
0.058690	236.0969	2.1802E-2

TABLE 8.7 TURBINE BLADE CROSS SECTION PRESSURE LOAD DATABASE  
HPFT STAGE 2 HUB CROSS SECTION

Average pressure (psia) 3923.184  
Inlet pressure (psia) 5916  
Radius (in) 4.603  
Scaling coefficient for the average pressure 0.6631

Number of nodes 35

X-coordinate (in)	Differential pressure (psia)	Scaling coef.
0.0	211.3819	1.9520E-2
0.058393	11.92897	1.1016E-3
0.116732	9.306971	8.5944E-4
0.173263	-65.3330	-6.0331E-3
0.232978	-88.2600	-8.1502E-3
0.287219	-128.380	-1.1855E-2
0.345420	-160.424	-1.4814E-2
0.401727	-178.244	-1.6460E-2
0.459065	-184.914	-1.7076E-2
0.573734	-200.283	-1.8495E-2
0.629677	-190.705	-1.7610E-2
0.687696	-156.798	-1.4479E-2
0.745695	-126.950	-1.1723E-2
0.785053	-98.9410	-9.1365E-3
0.819984	-73.9310	-6.8270E-3
0.841643	-55.8880	-5.1609E-3
0.857414	-38.8000	-3.5829E-3
0.847108	-40.7240	-3.7606E-3
0.819659	-38.4170	-3.5476E-3
0.777534	-28.8570	-2.6648E-3
0.739332	-19.3380	-1.7857E-3
0.686482	3.519971	3.2505E-4
0.631699	32.48497	2.9998E-3
0.575496	72.62497	6.7064E-3
0.516772	97.57197	9.0101E-3
0.458037	120.4889	1.1126E-2
0.399756	135.2859	1.2493E-2
0.344911	151.0619	1.3950E-2
0.287110	163.8239	1.5128E-2
0.234203	174.5069	1.6115E-2
0.172361	161.9449	1.4955E-2
0.116371	142.2219	1.3133E-2
0.097611	115.0189	1.0621E-2
0.059115	61.63597	5.6917E-3
-0.00099	210.3779	1.9427E-2

### The Turbine Blade 2519 Nodes FEM Static Pressures

ITBCOM = 1 & IBLOAD = 44

LDNAME = TB2519-P

The static pressures of the turbine blade are generated for the surface nodes of the blade. The scaling is carried out for the blade down to the platform only. For the shank portion of the blade, the reference static pressures are carried over as the static pressures for the nodes of the shank. The static pressures for all 2519 nodes of the FEM are evaluated. The static pressures of the non-surface nodes are equal to zero.

The scaling is performed cross section by cross section of the blade. For each blade cross section, the average pressure of all the surface nodes on the cross section is proportional to the turbine inlet pressure. The differential pressures of the surface nodes to the average pressure is proportional to the turbine torque.

$$P_{1,44,ij} = \frac{P_{avg,i}(ref)}{P_{inlet}(ref)} P_{inlet} + \frac{P_{ij}(ref) - P_{inlet}(ref)}{Torque(ref)} Torque$$

(8.3)

where,

$P_{1,44,ij}$  is the turbine blade static pressure of the i-th cross section and the j-th node

$P_{avg,i}(ref)$  is the reference average pressure of all surface nodes of the i-th cross section of the blade

$P_{inlet}(ref)$  is the reference turbine inlet pressure

$P_{inlet}$  is the turbine inlet pressure for the simulated configuration

$P_{ij}(ref)$  is the reference static pressure of the j-th node of the i-th cross section

$Torque(ref)$  is the reference torque of the turbine

$Torque$  is the torque of the turbine for the simulated configuration

$$P_{1,44,ij} = 0 \quad (1)$$

if the j-th node is not a surface node of the turbine blade

## COMPONENT STATIC PRESSURE LOADS

The component static pressure loads are calculated using a linear scaling model (LSCM). All static pressure loads in this group are correlated to a single system dependent variable and the scaling coefficients are constant.

The HGM Fuel Transfer Duct Inner Diameter Static Pressure

ITBCOM = 5 & IBLOAD = 2

LDNAME = HFTD-S-P

The load is the same as the HPFTP turbine discharge pressure which is one of the system variables (LDEP-ID = 60)

$$P_{5,2} = 1.0 * P_{0,60}$$

where,  $P_{i,j}$  stands for the pressure for component i and load-ID=2, i = 0 is for engine system dependent variable

The HGM Fuel Transfer Duct Outer Diameter Static Pressure

ITBCOM = 5 & IBLOAD = 5

LDNAME = HFTD-OSP

$$P_{5,5} = 1.0 * P_{0,58}$$

where  $P_{0,58}$  is the LPOTP turbine discharge pressure.

The LOX Post Top Position Inner Diameter Static Pressure  
(LOX Dome LOX Post Entrance Location)

ITBCOM = 6 & IBLOAD = 2

LDNAME = LOXPTISP

$$P_{6,2} = 1.0 * P_{0,15}$$

where  $P_{0,15}$  is the MCC oxidizer injector pressure.

The LOX Post Orifice Exit Underneath the LOX Dome Plate Inner Diameter Static Pressure

ITBCOM = 6 & IBLOAD = 3

LDNAME = LOXPMISP

$$P_{6,3} = 0.8972 * P_{0,15}$$

where  $P_{0,15}$  is the MCC oxidizer injector pressure.

The LOX Post Bottom (Exit Area) Inner Diameter Static Pressure  
ITBCOM = 6 & IBLOAD = 4  
LDNAME = LOXPBISP

$$P_{6,4} = 1.0 * P_{0,17}$$

where  $P_{0,17}$  is the MCC injector end pressure.

The LOX Post Mid Range (Between the LOX Dome Plate and the Secondary Faceplate) Outer Diameter Static Pressure  
ITBCOM = 6 & IBLOAD = 5  
LDNAME = LOXPMOSP

$$P_{6,5} = 1.0 * P_{0,16}$$

where  $P_{0,16}$  is the MCC hot gas injector pressure.

The HGM LOX Transfer Duct Static Pressure  
ITBCOM = 9 & IBLOAD = 2  
LDNAME = HOTD-S-P

$$P_{9,2} = 1.0 * P_{0,59}$$

where  $P_{0,59}$  is the HPOTP turbine discharge pressure.

The HGM LOX Transfer Duct Outer Liner Static Pressure  
ITBCOM = 9 & IBLOAD = 5  
LDNAME = HOTD-OSP

$$P_{9,3} = 1.0 * P_{0,57}$$

where  $P_{0,57}$  is the LPOTP turbine discharge pressure.

The HPOTP Discharge Duct Static Pressure  
ITBCOM = 10 & IBLOAD = 2  
LDNAME = HODD-S-P

$$P_{10,2} = 1.0 * P_{0,4}$$

where  $P_{0,4}$  is the HPOTP pump discharge pressure.

### 8.3 COMPONENT THERMAL LOADS

#### Thermal Load Modelling Approach

The thermal load models have been developed for three of the four components (hot gas manifold transfer ducts, HPFTP second stage turbine blade, and main injector LOX post). The fourth component, the HPOTP discharge duct, operates at constant temperature and does not require a model. The thermal load models are developed based on the methodology evolved over the years. The essential technique is as follows:

1. Reference thermal states (steady state and transient states at specific time slices) of the component obtained by deterministic thermal analyses are used as baseline temperature distributions across the component body.
2. The component is divided into regions of primary influence of a load variable or variables. A component could have just one region, such as the hot gas manifold transfer ducts. The method of division is to use specific reference isotherms (in the case of the turbine blade) or physical dimensions (in the case of the LOX post).
3. Each region is characterized by the maximum and minimum temperatures of that region. These temperatures are called the boundary thermal loads.
4. Influence relationships between the boundary loads and the engine system variables (hot gas and coolant temperatures, flowrates, etc.) and/or the component independent local (related to geometry and material properties) variables (hot gas heat transfer film coefficient factor, etc.) for each region are derived. The model using the influence equations to evaluate the boundary loads is called the thermal environment model. To be more general, the thermal environment model does not limit to an influence model. It can be a deterministic thermal analysis model that evaluate the boundary thermal loads.
5. The temperatures of the component within the region can then be calculated by scaling linearly based on the reference temperature distribution of the component at the desired states from the evaluated boundary temperatures.

#### CLS GENERIC THERMAL LOAD MODEL

The CLS thermal load model consists of two sub-models: the thermal load environment model and the thermal load evaluation model. The environment model simulates the component thermal load environment, evaluates the component temperature boundary condition values. The component thermal load evaluation model calculates the component temperatures based on the boundary conditions given by the environ-

ment model. It can be a full blown thermal analysis code or a simple scaling model. Hooking up a thermal analysis code to the CLS load module is not very complicated. It can be implemented easily.

The CLS generic thermal load model has a linear influence environment model and a linear scaling evaluation model. The linear influence environment model has the following form:

$$\frac{\Delta T_{bc,j}}{T_{bc,j}} = \sum_i (\text{infl. coeff})_i * \left( \frac{\Delta Y_i}{Y_i} \right) \quad (8.4)$$

where,

$T_{bc,j}$  is the j-th boundary load temperature

$\Delta T_{bc,j}$  is the change in  $T_{bc,j}$

$Y_i$  is the i-th engine system variable or component local variable

$\Delta Y_i$  is the change of  $Y_i$

$(\text{infl. coeff})_{ji}$  is the influence coefficient relating the i-th engine system variable to the j-th boundary load

The list of engine system variables and component local variables for each component includes the load variables and parameters that affect the boundary load temperatures of the component. The engine system variables are the engine dependent variables which in turn relate to the engine primitive (independent) variables. Their values are evaluated by the CLS engine system influence model. The component local variables are local to the component related to the geometric factors and material and flow properties. They are independent variables.

To evaluate  $T_{bc,j}$  from equation (8.4) one needs to know the mean values of the boundary loads at the power level being evaluated. These mean values are obtained from input or evaluated by a linear thermal mean value scaling model. The mean value scaling model is implemented only for the HPFTP turbine blade and the HGM fuel transfer duct. The mean value scaling model will be discussed in a later session.

The linear scaling evaluation model calculates the component nodal temperatures by scaling linearly from the boundary temperatures. The scaling is based on the reference temperatures of a steady state or a transient state at a specific time slice. The scaling equation is as follow:

$$\frac{T_i - T_{bc,1}}{T_{bc,2} - T_{bc,1}} = \frac{T_i(\text{ref}) - T_{bc,1}(\text{ref})}{T_{bc,2}(\text{ref}) - T_{bc,1}(\text{ref})} \quad (8.5)$$

where,

$T_i$  is the temperature of the i-th node to be evaluated

$T_{bc,1}$  is the maximum temperature boundary load

$T_{bc,2}$  is the minimum temperature boundary load

$T_i(\text{ref})$  is the reference temperature of the i-th node

$T_{bc,1}(\text{ref})$  is the reference maximum temperature

$T_{bc,2}(\text{ref})$  is the reference minimum temperature

Let  $cx_i$  be the ratio,

$$CX_i = \frac{T_i(\text{ref}) - T_{bc,1}(\text{ref})}{T_{bc,2}(\text{ref}) - T_{bc,1}(\text{ref})} \quad (8.6)$$

then, one has

$$T_i = (1 - CX_i) * T_{bc,1} + CX_i * T_{bc,2} \quad (8.7)$$

The ratio  $cx_i$  measures the thermal "distance" of the i-th node to the boundary nodes. Thus the scaling model is also called the thermal distance scaling model.

The model just presented is a generic thermal load model. It can be used for any component. It is implemented on CLS also as a generic load model. The boundary load variables and the lists of their associated system variables and component local variables are defined in database 'LCTH' and 'SCTH' of the CLS knowledge base, respectively. The coefficients of the linear influence environment model are stored in database 'ICTH'. These databases have been created for the HGM fuel transfer duct, the LOX post, and the 2519 nodes FEM and the 5000+ nodes FEM turbine blade thermal models. To implement the CLS generic thermal load model for a new component, all one needs are to define the corresponding LCTH, SCTH and ICTH databases for the new component and have a reference temperature file. This of course assumes that a thermal influence model has been developed for that component and a thermal analysis has been performed for the reference case.

#### Other thermal model options

There are two other thermal model options that are implemented on CLS. They are the mean value scaling model option and the environment model object function option. These two thermal models have exactly the same component thermal load linear scaling evaluation model as the CLS generic thermal load model. The difference is in

the environment model. The mean value scaling model is very similar to the linear influence model except that the nominal reference load values are fixed at a chosen power level. The model assumes that the changes are linear over a wide range of power level. For simplicity, the coefficients of the mean value scaling model are hardwired to the component thermal load object functions. The model is implemented only for the HPFTP turbine blade and the HGM fuel transfer duct. Since it is available for these two components, there is an option to use the mean value scaling model to calculate the mean values of the boundary loads for use in the linear thermal influence model.

The environment model object function option is provided for implementing a more complex model such as a quadratic influence model. The object function implementation follows the object oriented programming philosophy. The environment model object function is written for each individual component environment model with built-in coefficients. It is easy to build even for a very complicated model. It achieves data encapsulation but loses the generality. The quadratic influence thermal load model of the LOX post is implemented this way.

#### Expert System Thermal Load Rule Module

The thermal load model option of the expert system rule module ANLDIN for preparing an input file INFILE for a thermal load simulation is implemented. The rule module knows what boundary load variables are required for a user's component thermal load simulation and automatically retrieves their mean values and relevant influence coefficients. It knows what system dependent loads are needed for the thermal load model and it can select the most influential primitive variables for the analysis. It will also automatically retrieve the load information of the engine variables and the influence coefficients needed for the engine system performance calculation. All these information and data are provided in the databases. There is no hardwired code to provide the information.

The Turbine Blade Thermal Load  
ITBCOM=1 & IBLOAD=25

The turbine blade thermal load model evaluates the turbine blade steady state temperatures of selected nodes of the 2519 nodes turbine blade finite element model (FEM) for an engine condition. The model first evaluates a set of boundary conditions for the particular engine conditions using the thermal environment influence model. For the turbine blade thermal load, the boundary condition loads are the maximum temperature and the minimum temperature of the blade, the hot gas temperature and the coolant mixing temperature.

The controlling dependent loads of these boundary loads are the turbine inlet and discharge temperatures, the pump discharge temperature and the two geometric factors accounting for the hot gas and the coolant leakage into the shank areas of the blade.

$$\% \text{ of max.Twg} = 0.8269 * (\% \text{ of Tout}) + 0.1731 * (\% \text{ of Tin})$$

$$\% \text{ of min.Twc} = 0.2283 * (\% \text{ of Tp}) - 0.7872 * (\% \text{ of Gc})$$

$$\begin{aligned} \% \text{ of Tm1} &= 0.00798 * (\% \text{ of Tp}) + 0.1682 * (\% \text{ of Tin}) + \\ &0.8038 * (\% \text{ of Tout}) + 1.0 * (\% \text{ of Gb}) + \\ &- 0.0275 * (\% \text{ of Gc}) \end{aligned}$$

{ In CLS, the boundary load Til is used instead of Tm1 }  
{ Tm1 is for isotherm T=1650°R }  
{ Til is for isotherm T=1760°R }

$$\begin{aligned} \{ \% \text{ of Til} &= 0.003767 * (\% \text{ of Tp}) + 0.1708 * (\% \text{ of Tin}) + \} \\ \{ &0.8160 * (\% \text{ of Tout}) + 0.4716 * (\% \text{ of Gh}) - \} \\ \{ &0.01298 * (\% \text{ of Gc}) \} \end{aligned}$$

$$\begin{aligned} \% \text{ of Tm2} &= 0.0563 * (\% \text{ of Tp}) - 0.1942 * (\% \text{ of Gc}) + \\ &0.6639 * (\% \text{ of Tout}) + 0.1389 * (\% \text{ of Tin}) + \\ &0.8259 * (\% \text{ of Gh}) \end{aligned}$$

where (% of Var) means the percentage change of the variable Var, i.e.

$$\% \text{ of Var} = \frac{\text{Var}_2 - \text{Var}_1}{\text{Var}_1}$$

The thermal load model then evaluates the turbine blade temperatures with a scaling model. The reference temperatures used in the scaling model were generated by a 3D turbine blade thermal

analysis at the FPL (109% power level) operating condition. The scaling equation is

$$\frac{T_i - T_{b1}}{T_{b2} - T_{b1}} = \frac{T_i(\text{ref}) - T_{b1}(\text{ref})}{T_{b2}(\text{ref}) - T_{b1}(\text{ref})} \quad (8.8)$$

where,

T is the temperature of a node on the blade to be evaluated

T<sub>b1</sub> and T<sub>b2</sub> are the evaluated boundary condition temperatures of the region

T<sub>b1</sub>(ref) and T<sub>b2</sub>(ref) are the reference boundary condition temperatures for the region of interest

the four boundary condition loads are:

the reference maximum blade temperature Ref.max.Twg = 1860 R

the reference minimum blade temperature Ref. min.Twc = 399 R

the reference first mixed gas temperature Ref. Tm1 = 1660 R

the reference first isotherm temperature Ref. Til = 1760 R

the reference second mixed gas temperature Ref. Tm2 = 1005 R

The thermal mean value scaling model for the 2519 nodes FEM turbine blade model is as follows:

$$Twg = 0.84 * Tout + 0.16 * Tin$$

$$Tm1 = 0.7287 * Tout + 0.1388 * Tin + \\ 0.1325 * Tp + 1660 * Gh - \\ 45.69 * Gc - 1581.2$$

$$\begin{array}{l} \{ Or \\ \{ \quad Til = 0.7844 * Tout + 0.1494 * Tin + \\ \{ \quad \quad 0.0663 * Tp + 830 * Gh - \\ \{ \quad \quad 22.834 * Gc - 790.594 \end{array} \}$$

$$Tm2 = 0.3644 * Tout + 0.0694 * Tin + \\ 0.566 * Tp + 830 * Gh - \\ 195.2 * Gc - 493.2$$

$$Twc = Tp - 344.8 * Gc + 643.8$$

The HPFTP Second Stage Turbine Blade 5000+ Nodes FEM  
ITBCOM = 1 & IBL0AD = 50

Thermal environment model influence equation

$$\% \text{ of Max. Twg} = 0.8269 * (\% \text{ of Tout}) + 0.1731 * (\% \text{ of Tin})$$

$$\begin{aligned} \% \text{ of Tm1} &= 0.8038 * (\% \text{ of Tout}) + 0.1682 * (\% \text{ of Tin}) + \\ &0.00798 * (\% \text{ of Tp}) + 1.0 * (\% \text{ of Gh}) - \\ &0.0275 * (\% \text{ of Gc}) \end{aligned}$$

$$\begin{aligned} \% \text{ of Tm2} &= 0.6639 * (\% \text{ of Tout}) + 0.1389 * (\% \text{ of Tin}) + \\ &0.0563 * (\% \text{ of Tp}) + 0.8259 * (\% \text{ of Gh}) - \\ &0.1942 * (\% \text{ of Gc}) \end{aligned}$$

$$\% \text{ of Min. Twc} = 0.2801 * (\% \text{ of Tp}) - 0.9658 * (\% \text{ of Gc})$$

The thermal scaling evaluation model for the 5000+ nodes FEM is the same as the 2519 nodes FEM one.

For the thermal transient load model, the influence coefficients of the thermal environment model remains the same. However, the complete FEM is considered to be a single region. Only two of the boundary loads, the maximum hot gas wall temperature and the minimum coolant wall temperature, are used to scale the thermal load with the two influence equations, one for the maximum hot gas wall temperature and one for the minimum coolant wall temperature.

Since the temperature distribution across the body of the turbine blade is changing during the transient, different reference temperature profiles are used for different time slices. The file contains the transient reference temperature profiles is 'su6.pst81' for the start transient and 'co4.pst81' for the shutdown transient.

The start transient file 'su6.pst81' contains the nodal coordinates and 62 time slices of temperature profiles. Each time slice has temperatures for all 5561 nodes. The 62 time slices have the following times:

Time (interval=0.2) = 0, 0.2, 0.4  
Time (interval=0.05) = 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8,  
0.85, 0.9, 0.95, 1.0, 1.05, 1.1, 1.15, 1.2,  
1.25, 1.3, 1.35, 1.4  
Time (interval=0.2) = 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0,  
3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6,  
4.8, 5.0  
Time (interval=0.5) = 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0,  
9.5, 10.0  
Time (interval=1.0) = 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0,  
18.0, 19.0, 20.0, 20.0

The shutdown transient file 'co4.pst81' contains the nodal coordinates and 51 time slices evenly distributed from time = 0 for the start of engine cut-off to time = 5 at the engine cut-off time plus 5 seconds for the end of the shutdown transient. The time interval is 0.1 second. The strategy employed for the transient temperature simulation is as follows:

(1) For the start transient, for time not falling on one of the time slice, the reference temperatures of the time slice having time large than the time of interest and yet closest to it are used in the simulation.

(2) For the shutdown transient, the time slice earlier than the time of interest and closest to it is employed in the simulation.

The procedure is automated in the code and does not require user intervention.

The HGM Fuel Center Transfer Tube Thermal Load  
ITBCOM=5 & IBLOAD=25

The HGM (Hot Gas Manifold) fuel center transfer tube thermal load model was implemented the same way as the turbine blade thermal model. The boundary condition loads for the influence model are the maximum tube wall temperature and the minimum tube wall temperature.

The controlling dependent loads are the hot gas temperature and the coolant temperature.

$$\% \text{ of max.Twg} = 0.99962 * (\% \text{ of Tg})$$

$$\% \text{ of min.Twc} = 0.99432 * (\% \text{ of Tc})$$

The scaling is done the same way as the turbine blade thermal model.

$$\frac{T - \min.T_{wc}}{\max.T_{wg} - \min.T_{wc}} = \frac{\text{Ref.T} - \text{Ref.min.T}_{wc}}{\text{Ref.max.T}_{wg} - \text{Ref.min.T}_{wc}}$$

where,

T is the temperature of a node on the transfer tube to be evaluated,

the reference maximum wall temperature Ref.max.Twg = 1558.5°R

the reference minimum wall temperature Ref. min.Twc = 494.9°R

The Main Injector LOX Post Thermal Load  
ITBCOM = 6     &     IBLOAD = 25

The thermal environment model is implemented as a thermal environment model object function due the complexity of the model. It is a quadratic influence model. The influence equations are as follows:

For region 1  
with the axial coordinate  $Z < 0.78$  in.,

$$\begin{aligned}(\% \text{ of Max. Twg}) = & 0.9489*(\% \text{ of Tg}) \\ & + 0.0863*(\% \text{ of FLg}) - 0.1642*(\% \text{ of FLg})^2 \\ & - 0.0423*(\% \text{ of MR}) + 0.0117*(\% \text{ of MR})^2 \\ & + 0.11*(1.0 - \text{EXP}(-122.62*\text{Gap})) \\ & + 0.1388*(\% \text{ of Gh}) - 0.105*(\% \text{ of Gh})^2\end{aligned}$$

$$(\% \text{ of Min. Twc}) = 1.0*(\% \text{ of Tc})$$

For region 2  
with the axial coordinate satisfying  $\{ 0.78 \text{ in.} < Z < 2.14 \text{ in.} \}$ ,

$$\begin{aligned}(\% \text{ of Max. Twg}) = & 0.9604*(\% \text{ of Tg}) \\ & + 0.069*(\% \text{ of FLg}) - 0.1504*(\% \text{ of FLg})^2 \\ & - 0.0343*(\% \text{ of MR}) + 0.0061*(\% \text{ of MR})^2 \\ & + 0.1153*(\% \text{ of Gh}) - 0.0988*(\% \text{ of Gh})^2\end{aligned}$$

$$\begin{aligned}(\% \text{ of Min. Twc}) = & 0.2147*(\% \text{ of Tg}) \\ & + 1.0257*(\% \text{ of Tc}) \\ & - 0.0895*(\% \text{ of FLc}) + 0.2651*(\% \text{ of FLc})^2 \\ & - 0.157*(\% \text{ of Gc})\end{aligned}$$

For region 3  
with  $Z > 2.14$  in.

$$\begin{aligned}(\% \text{ of Max. Twg}) = & 0.99*(\% \text{ of Tg}) \\ & + 0.028*(\% \text{ of FLg}) - 0.0962*(\% \text{ of FLg})^2 \\ & - 0.0156*(\% \text{ of MR}) + 0.0141*(\% \text{ of MR})^2 \\ & + 0.0575*(\% \text{ of Gh}) - 0.0523*(\% \text{ of Gh})^2\end{aligned}$$

$$\begin{aligned}(\% \text{ of Min. Twc}) = & 0.7332*(\% \text{ of Tg}) \\ & + 1.0502*(\% \text{ of Tc}) \\ & + 0.0917*(\% \text{ of FLg}) - 0.1363*(\% \text{ of FLg})^2 \\ & - 0.2323*(\% \text{ of FLc}) + 2.2125*(\% \text{ of FLc})^2 \\ & + 0.138*(\% \text{ of Gh}) - 0.092*(\% \text{ of Gh})^2 \\ & - 0.6623*(\% \text{ of Gc}) + 1.0762*(\% \text{ of Gc})^2\end{aligned}$$

Notice in the influence equation for the maximum hot gas wall temperature of region 1, the exponential term for the Gap size. Since the nominal value for the gap size is zero gap, an exponential model is more appropriate than the polynomial terms. The thermal scaling evaluation model is the standard LSEM model.

## 8.4 DUCT DYNAMIC PRESSURE (FLUCTUATING PRESSURE) LOADS

### The Duct Pressure Fluctuation Model

The dynamic pressure load on ducts is the pressure fluctuation exerted to the duct due to the turbulence flow condition inside the duct. The generic pressure fluctuation model was developed (Ref's 4, 15-17) to provide a fluctuation pressure load in the form of a pressure power density spectrum (PSD) and correlation lengths for flows through the ducts at different locations. This load is implemented on the expert system rule module ?EXDR/FPSP. It is not included in the load module of the CLS load simulation module ANLOAD because it does not require load simulation.

The fluctuation pressure PSD of the ducts under investigation (for the Composite Load Spectra project, it is the Hot Gas Manifold transfer ducts, the LOX posts and the HPOTP discharge duct) has the following general shape as shown in Fig. 8.1:

$$\phi(f) = k_0 * f^{-s} \quad \text{for } f_0 < f < f_1$$

$$\phi(f) = k_1 * f^{-5/3} \quad \text{for } f_1 < f < f_2$$

where,

s is the shape factor, can be either 1.0 or 0.4, depending on the component and the geometry location

f<sub>1</sub> is the frequency beyond which inertial subrange is in effect, it is chosen in general at 40% of the entire frequency band (f<sub>1</sub>)

f<sub>2</sub> represents the range to which the spectra is of interest.

k<sub>0</sub> and k<sub>1</sub> are the normalization factors, to be determined by the integral of  $\phi(f)$  over the range of frequencies from f<sub>0</sub> to f<sub>1</sub>. It is assumed that the integral equal to 81% of the root-mean-square power of the fluctuating pressure PSD.

The PSD is normalized to the root-mean-square fluctuation pressure p' which is proportional to the 1-D flow dynamic head q<sub>1-D</sub>. The p'/q<sub>1-D</sub> ratio is an empirical parameter developed based on experimental data. It varies with the flow geometry and flow separation characteristics. The values used in the model will be based on existing experimental data and engineering estimates of our expert if data does not exist. The PSD is generated by subroutine PSDPR. Figures 8.2 and 8.3 show the PSD predictions of the above formulas for the HGM oxidizer upper transfer duct at the entrance top position and the fuel upper transfer duct at the entrance bottom position. In Fig. 8.3, the shape factor s of 0.4 gives a better fit to the PSD.

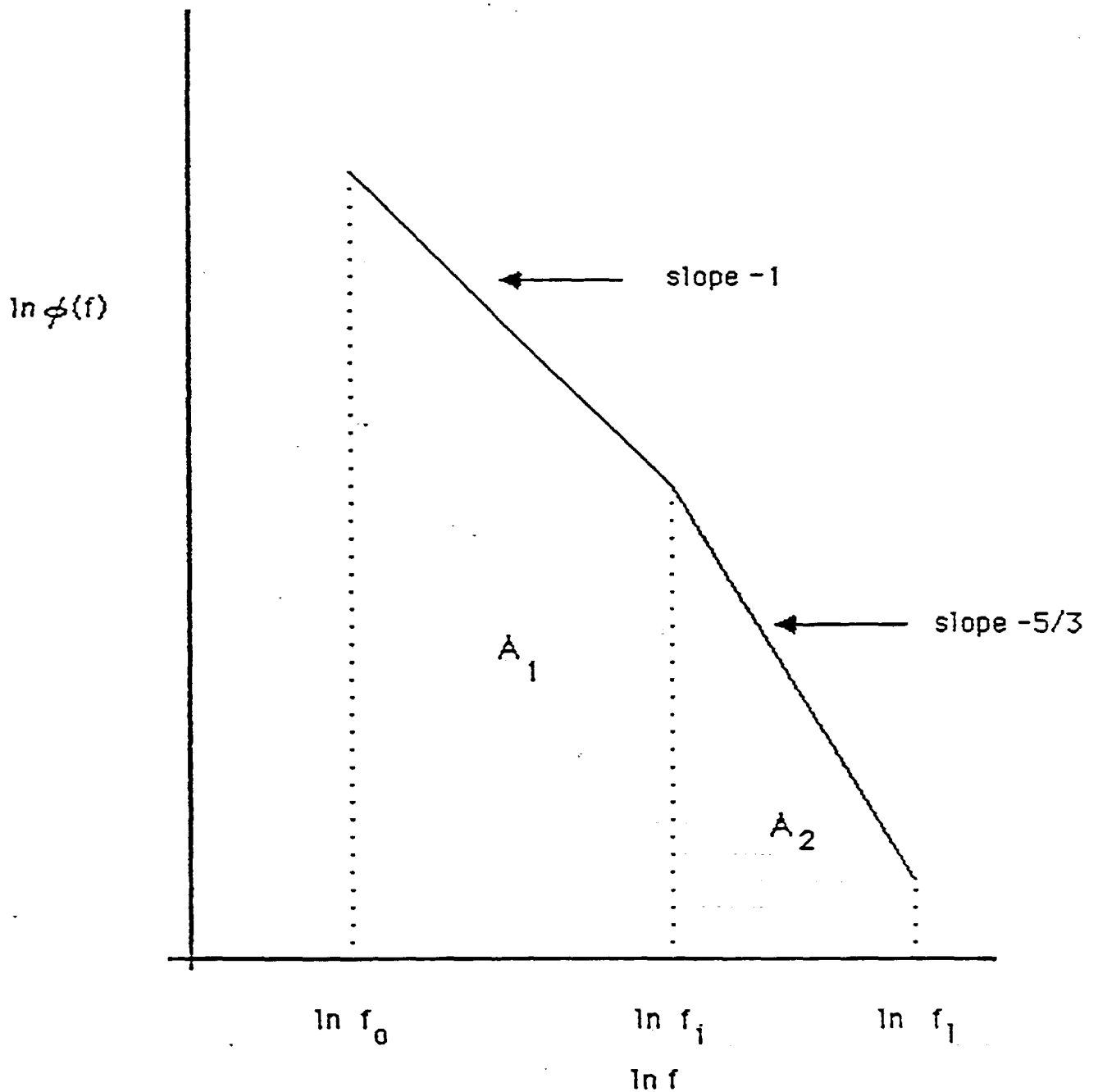


Figure 8.1 Generic Fluctuating Pressure Power Spectral Density (PSD) for SSME Ducts

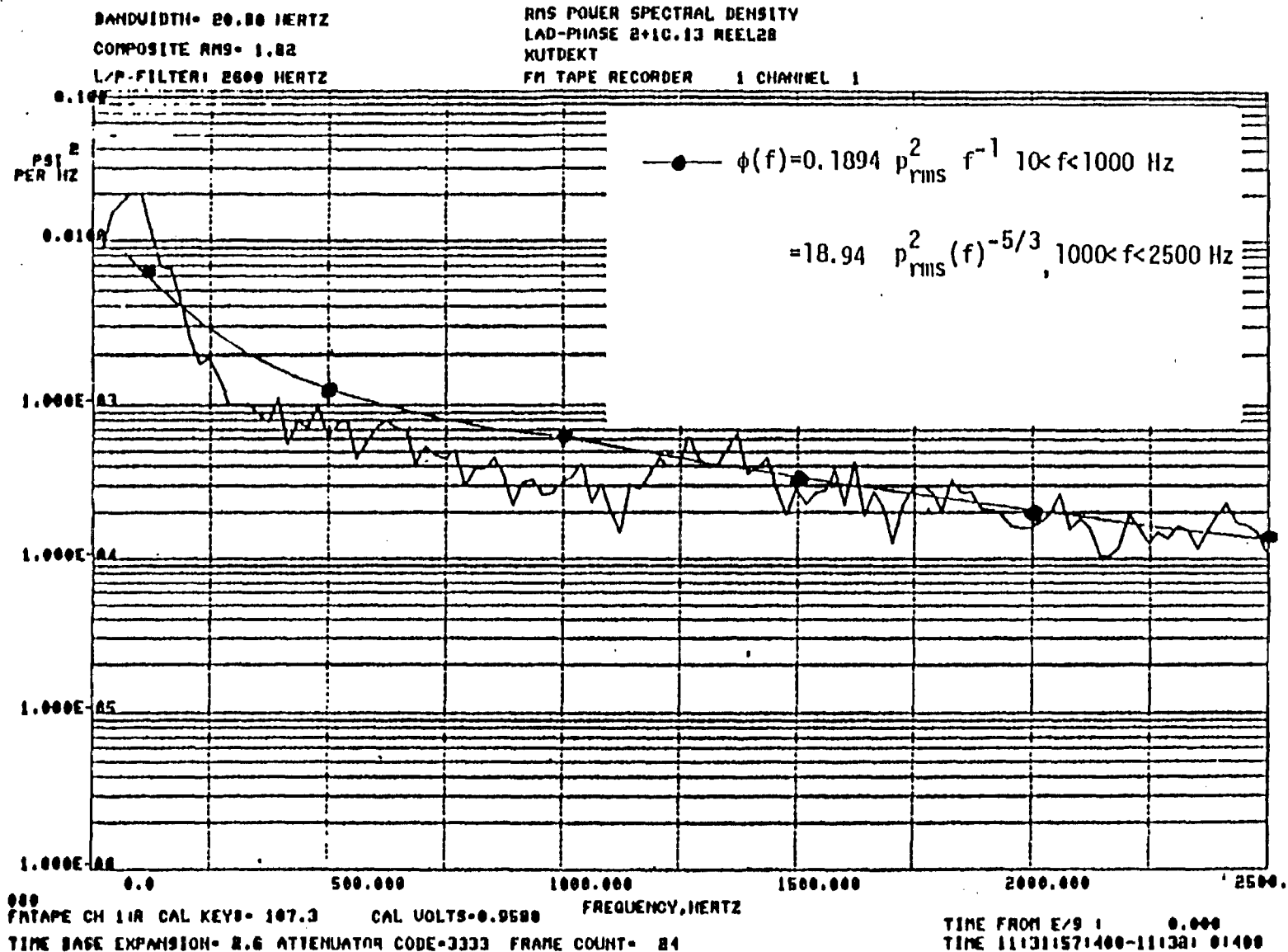


Figure 8.2 Comparison of the Generic Fluctuating Pressure PSD and the Measured Root-Mean-Square PSD of the HGM Oxidizer Upper Transfer Duct at the Entrance Top Position

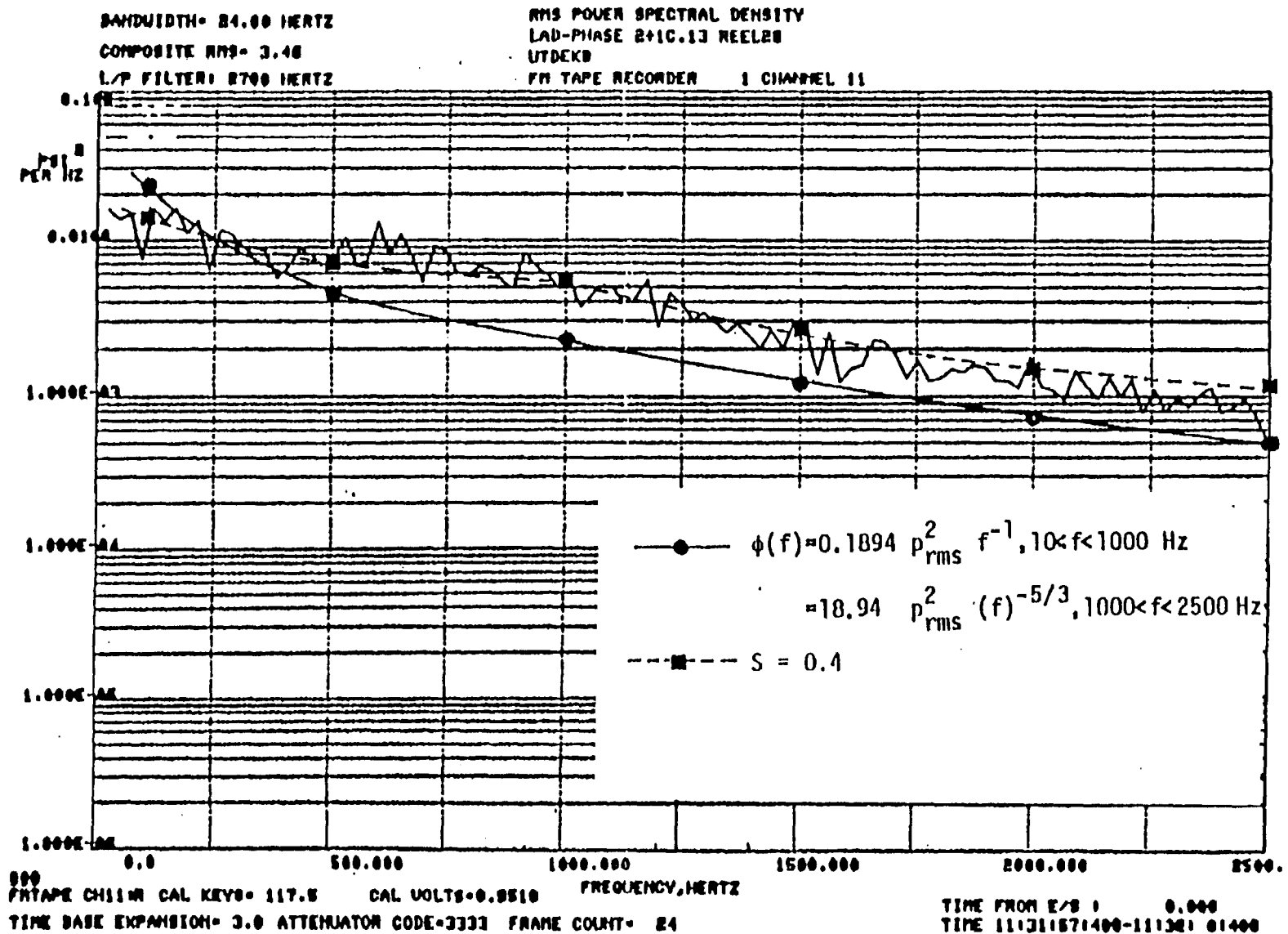


Figure 8.3 Comparison of the Generic Fluctuating Pressure PSD and the Measured Root-Mean-Square PSD of the HGM Fuel Upper Transfer Duct at the Entrance Bottom Position

The correlation length  $L_x$ , over which the pressure fluctuation acts, is calculated in subroutine CORLEN. It is evaluated as follows:

$$L_x = U_c * T_x$$

$$T_x = \int_0^{\infty} R(\tau) d\tau$$

$$R(\tau) = \int_0^{\infty} \phi(\omega) \cos(\omega\tau) d\omega$$

where,

$U_c = 0.6 * U_{1-D}$  for a boundary layer flow,

$U_c$  is the convection velocity of the large scale eddies,

$U_{1-D}$  is the freestream velocity

The model implemented is generic to the components of interest. Three databases are required. The first database is the dependent load information on flow velocity and dynamic head for each component. The second database is the coarse geometry information related to the ratio of the 1-D (one dimension) root-mean-square pressure to the flow dynamic head. This ratio relates to the turbulent intensity factor of the flow and is geometry dependent. The third database is the pressure fluctuation parameter database. One of the parameters is the geometry dependent ratio related to the turbulent intensity. Therefore, the parameter database has entries for each coarse geometry region. Examples of the second and third databases are listed below for the HPOTP discharge duct.

DUCT : The geometry database for ducts

```
COMP-ID : 10          /* HPOTP
C-L-ID   : 33          /* Component Fluctuation Pressure Load
N-ZONES  : 6           /* Number of coarse zones
LOC-1    : STRAIGHT    /* Straight portion of the duct
LOC-2    : TURN1ALL    /* All area of the wall of the first
                        /* turn
LOC-3    : TURN2TOP    /* Top wall of the turn #2
LOC-4    : TURN2BOT    /* Bottom wall of the turn #2
LOC-5    : TURN3TOP    /* Top wall of the turn #3
LOC-6    : TURN3BOT    /* Bottom wall of the turn #3
```

CLFP : The component fluctuation pressure load parameter database

```
COMP-ID : 10
C-L-ID   : 33
C-L-NA   : HODD-F-P    /* HPOTP Discharge Duct Fluctuation Pr.
LOC-DUCT : TURN1ALL    /* Location of the duct
DIA-EQV  : 0.333       /* Equivalent diameter in ft
FI-RATIO : 0.15        /* Fluctuation intensity ratio, i.e.
                        /* the ratio of the 1-D root-mean-
                        /* square pressure to the flow dynamic
                        /* head
CORLEN   : 0.175       /* Nominal fluctuation pressure
                        /* correlation length, CORLEN is
                        /* an evaluated variable, calculated in
                        /* subroutine CORLEN
SHAPE-F  : 0.4         /* Shape factor
FREQ-0   : 10          /* PSD frequency lower bound in Hz
FREQ-I   : 4000        /* PSD intermediate frequency in Hz
FREQ-L   : 10000       /* PSD cut-off frequency in Hz
A-L-FREQ : 0.81        /* Percentage area under the low
                        /* frequency portion of the PSD
```

The fluctuation pressure load model is available in the load expert system module ?EXDR/FPSM. To activate the model, do the following:

- (1) Run the expert system code by entering: ldrbms51
- (2) When prompt for expert system module, enter: ?EXDR
- (3) Select the FPSM module from the expert system menu by entering: FPSM

HGM Fuel Transfer Duct Fluctuating Pressure Load  
ITBCOM = 5 & IBLOAD = 33  
Duct location: DUCT-ALL

It is assumed that the fluctuating pressures everywhere on the HGM fuel transfer duct are the same. Therefore, only one location "DUCT-ALL" of the duct is evaluated.

The fluctuating load is evaluated by the expert system module: ?EXDR/FPSM (duct fluctuating pressure scaling model).

(1) The expert system will prompt user for component ID and duct location and retrieve a CLFP database for the component associated with the particular location.

(2) The module will then call in the QLM (quick look model) module to evaluate the fuel 1-Dimension flow velocity and dynamic pressure. This is where the dynamic pressure load is coupled to the engine system variables. The module will prompt user at what percentile the system variables are to be evaluated.

(3) The module will then evaluate the duct fluctuating pressure PSD, autocorrelation spectrum and correlation length using Dr. Sharma's duct fluctuating pressure scaling model.

The CLFP database for the HGM fuel transfer duct is

Database Field	Field-Value
CMFN-ID	5
C-LD-ID	33
C-LD-NA	HFTD-F-P
LOC-DUCT	DUCT-ALL
DIA-EQV	0.54
FI-RATIO	0.15
CORLEN	0.298
SHAPE-F	1.0
FREQ-0	1.0000E+01
FREQ-I	1.0000E+03
FREQ-L	2.5000E+03
A-L-FREQ	0.81

LOX Post Fuel Side Fluctuating Pressures Load

ITBCOM = 6 & IBLOAD = 33

Available duct locations:

P0102TOP : Top location of LOX Posts in the 01-02 area  
P0102MID : Middle location of LOX Posts in 01-02 area  
P0102BOT : Bottom location of LOX Posts in 01-02 area  
P7778TOP : Top location, in 77-78 area  
P7778MID : Middle location, in 77-78 area  
P7778BOT : Bottom location, in 77-78 area  
P7273TOP : Top location, in 72-73 area  
P7273MID : Middle location, in 72-73 area  
P7273BOT : Bottom location, in 72-73 area  
P7071TOP : Top location, in 70-71 area  
P7071MID : Middle location, in 70-71 area  
P7071BOT : Bottom location, in 70-71 area

The CLFP database information

<u>LOC-DUCT</u>	<u>FI-RATIO</u>
P0102TOP	1.06
P0102MID	0.876
P0102BOT	0.67
P7778TOP	0.69
P7778MID	0.96
P7778BOT	1.22
P7273TOP	0.66
P7273MID	0.89
P7273BOT	1.09
P7071TOP	0.55
P7071MID	0.72
P7071BOT	0.88

For the LOX posts on the fuel side, the flow dynamic pressure load is not available in the engine system model. In this case, the mass flowrate of the flow is used to calculate the 1-D (one dimension) flow velocity and its dynamic head (pressure).

# HGM Oxidizer Transfer Duct Fluctuating Pressure Load

ITBCOM = 9 & IBLOAD = 33

## Available duct locations:

TOP-ALL : All locations on the top wall of the duct  
BOT-ENTR : Duct bottom wall entrance area  
BOT-REST : Duct bottom wall area other than the entrance

## The CLFP database information

<u>LOC-DUCT</u>	<u>FI-RATIO</u>
TOP-ALL	0.15
BOT-ENTR	0.30
BOT-REST	0.15

# HPOTP Discharge Duct Fluctuating Pressure Load

ITBCOM = 10 & IBLOAD = 33

## Available duct locations:

STRAIGHT : Straight portion of the HPFTP discharge duct  
TURN1ALL : All locations on the 1st turn of the duct  
TURN2TOP : Top wall on the 2nd turn  
TURN2BOT : Bottom wall on the 2nd turn  
TURN3TOP : Top wall on the 3rd turn  
TURN3BOT : Bottom wall on the 3rd turn

## The CLFP database information:

<u>LOC-DUCT</u>	<u>FI-RATIO</u>
STRAIGHT	0.15
TURN1ALL	0.15
TURN2TOP	0.15
TURN2BOT	0.30
TURN3TOP	0.15
TURN3BOT	0.30

## 8.5 Programmer's Notes

The code module CLSICM is the load model for the SSME engine load simulation. The structure of the module is depicted in Fig. 8.4.

<u>Driver</u>	<u>Engine Model</u>	<u>Component Objects</u>	<u>Component Loads</u>
CLSICM	CLLDDB	CLTBLD	BLXSP4
	OBSICM	CLFTRD	BLDYP
	CLOBJS	CLLOXP	THENVR
		CLHODD	THER01
		CLMCCL	TBSCTH
		CLALSC	TBTRTH
		NLSMCC	RDTBTT
			THER05
			TDSCTH
			RDHGMD
			THER06
			ENLXPT
			LXSCTH
			RDLOXT
			THER15
			OMCCLN
			CLLSCM

OBSICM is the engine influence model.

CLOBJS is the component load objects driver routine.

CLTBLD is the turbine blade load object function with object ID IDOBJ=1.

CLFTRD is the Hot Gas Manifold fuel transfer duct load object function with IDOBJ=5.

CLLOXP is the LOX post load object function with IDOBJ=6.

CLHODD is the HPOTP discharge duct load object function with IDOBJ=10.

CLMCCL is the MCC liner load object function with IDOBJ=12.

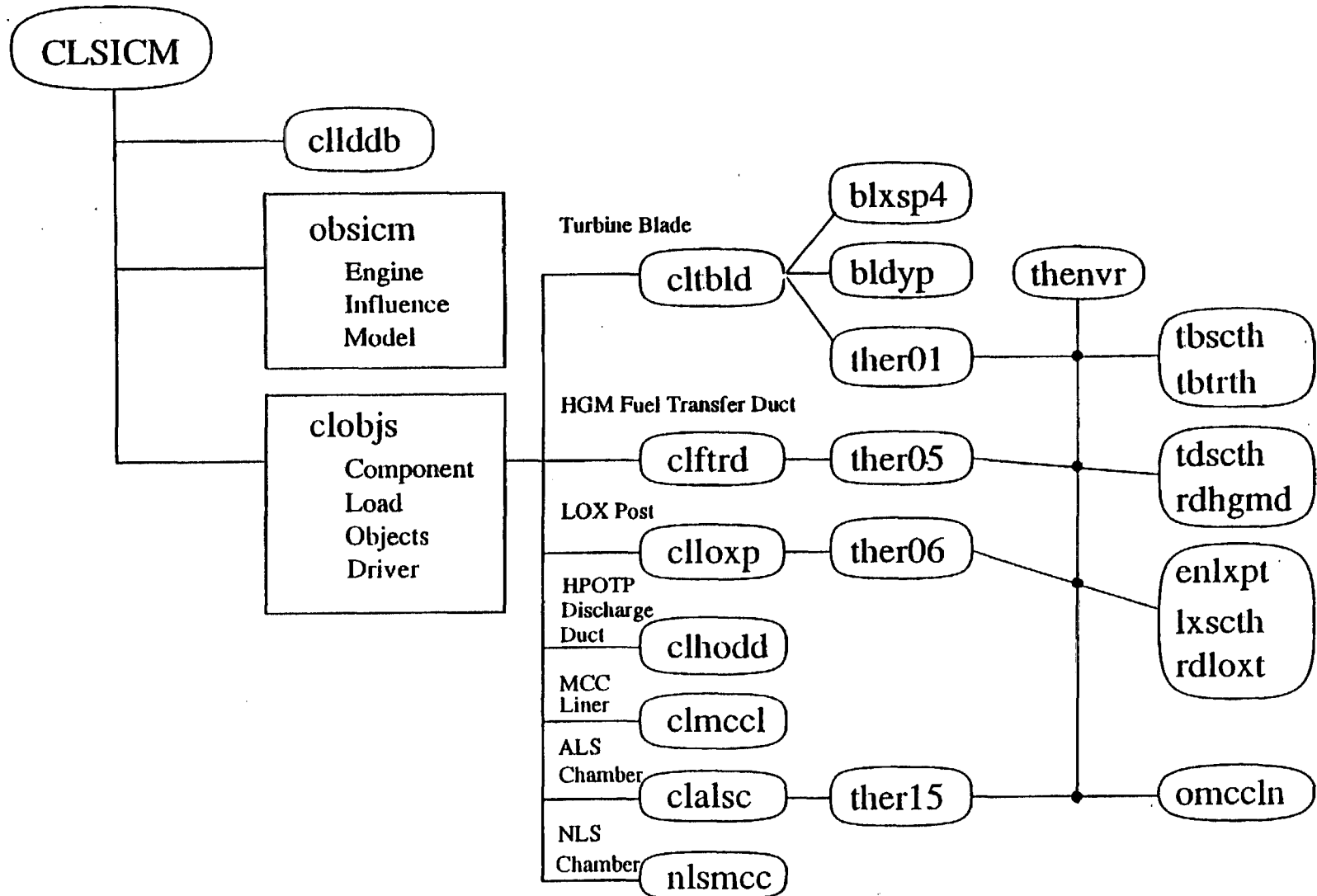
CLALSC is the Advanced Launch System MCC liner load object function with IDOBJ=15.

NLSMCC is the National Launch System MCC liner load object function with IDOBJ=112.

PP1 and PP2 arrays used through out the CLSICM module. PP1's are the load values and PP2's are the load deviation from their mean values. The arrays are ordered as follows:

PP1(1) - PP1(NOUT) : component load values for component load  
i = 1, ... , NOUT, where NOUT is the number  
of component loads including component local  
variables to be evaluated in a simulation

Figure 8.4 CLS Load Module CLSICM



PP1(NOUT+1) - PP1(NOUT+NRESP) :  
values of engine system dependent loads or  
variables, NRESP is the number of the system  
dependent variables

PP1(NOUT+NRESP+1) - PP1(NOUT+NRESP+NLOAD) :  
values of engine primitive variables (engine  
independent variables, NLOAD is the number  
of engine primitive variables

PP1(NOUT+NRESP+NLOAD+1) - PP1(NOUT+NRESP+NLOAD+NGF) :  
values of component (independent) local  
variables, NGF is the number of component  
local variables required to evaluate the  
values of component loads

PP2 array uses the same indexing scheme. PP2(i) is the load  
deviation of PP1(i) from its mean value.

The load module driver routine CLSICM stores the load or variable  
values into the PP1 & PP2 arrays. It prints out the intermediate  
results (the evaluated load/variable values from each call to the  
load module CLSICM) every other MPRT calls to CLSICM. For example,  
MPRT=1 will cause the print out of the intermediate results for all  
calculation (every call to CLSICM). CLSICM also save all interme-  
diate results into a file named SCLMSAV. If SCLMSAV is to be saved  
for later use, its name needs to be changed to a distinct file  
name.

SCLMSAV file format:

1) FORMAT(12I6)	/* NOUT is the number of
NOUT,NRESP,NIRV,NXS	/* component loads.
	/* NRESP is the number of system
	/* dependent loads.
	/* NIRV is the number of
	/* independent variables
	/* NIRV = NLOAD+NGF
	/* NLOAD is the number of engine
	/* independent variables. NGF is
	/* the number of component local
	/* variables
2) FORMAT(12I6)	/*
ITBCOM(i), i=1,NOUT	/* ITBCOM(i) is the component ID
3) FORMAT(12I6)	/*
IBLOAD(i), i=1,NOUT	/* IBLOAD(i) is the component
	/* load ID
4) FORMAT(12I6)	/*
ICOMB(i), i=1,NRESP	/* ICOMB(I) is the system
	/* dependent load ID
5) FORMAT(12I6)	/*
IDIRV(i), i=1,NIRV	/* IDIRV(i) is an independent
	/* variable ID

```

6) FORMAT(I6)                                /*
NOCTT                                         /* NOCTT is the total number of
                                              /* all nodal loads.

7) FORMAT(12I6), if NOCTT > 0,
J,NOCAL(J),NODETM(J),NODEST(J),NODEBG(J) for J=1,NOUT
/* NOCAL(j) is number of nodal
/* load for j-th component load.
/* NODETM(j) is the total number
/* of nodes of a FEM.
/* NODEST(j) is the nodal step
/* size for the simulation.
/* NODEBG is the beginning node
/* for simulation.

8) FORMAT(I12,2(1PE12.5))
NORUN,TIME,PL                                /* NORUN is the run number.
                                              /* NORUN = NORUN+1 for each call
                                              /* to CLSICM.
                                              /* TIME is the time of the
                                              /* simulation step.
                                              /* PL is the power level of the
                                              /* simulation step.

9) FORMAT(6(1PE12.5))
PP1(i), i=1,NOUT+NRESP+NIRV                 /* PP1's are the load values
10)FORMAT(6(1PE12.5)), if NOCTT > 0,
OUTDRV(i), i=IPTOBG,IPTOUT                   /* OUTDRV's are the saved nodal
                                              /* load values of a FEM

```

Repeat lines 8 to 10 for each NORUN

## References

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- 9) Rajagopal, K. R., J. Keremes, H. Ho and G. Orient, April 1992, "A PROBABILISTIC APPROACH TO THE EVALUATION OF FATIGUE DAMAGE IN A SPACE PROPULSION SYSTEM INJECTOR ELEMENT," AIAA 33rd Structures, Structural Dynamics and Materials Conference, Dallas, Texas
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- 11) Newell, J. F., K. R. Rajagopal, H. Ho and J. M. Cunniff, 1990, "PROBABILISTIC FAILURE ANALYSIS OF SPACE PROPULSION SYSTEM MAIN COMBUSTION CHAMBER LINER," Rocketdyne, Rockwell International, unpublished
- 12) Newell, J. F., K. R. Rajagopal, H. W. Ho and J. M. Cunniff, April 1990, "PROBABILISTIC STRUCTURAL ANALYSIS OF SPACE PROPULSION SYSTEM LOX POST," AAIA 31st Structures, Structural Dynamics and Materials Conference, Long Beach, California
- 13) Rajagopal, K. R., J. Keremes, H. Ho and G. Orient, April 1992, "A PROBABILISTIC APPROACH TO THE EVALUATION OF FATIGUE DAMAGE IN A SPACE PROPULSION SYSTEM INJECTOR ELEMENT," AIAA 33rd Structures, Structural Dynamics and Materials Conference, Dallas, Texas
- 14) Orient, G., H. Ho, K. R. Rajagopal, and M. McGaw, November 17-18, 1992, "DEVELOPMENT OF LIFE PREDICTION CAPABILITIES FOR SSME MCC LINER," Fourth Annual Space System Health Management Technology Conference for Space Propulsion System, Cincinnati, Ohio
- 15) Sharma, L. K., December 1987, "Transfer Duct Pressure Fluctuations and Correlation Lengths for the Composite Load Spectra Program," SSME-87-1756, Rocketdyne, Rockwell International
- 16) Sharma, L. K., December 1987, "HPOP Discharge Duct Pressure Fluctuations and Correlation Lengths for the Composite Load Spectra Program," SSME-87-1757, Rocketdyne, Rockwell International
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## **APPENDIX I**

### **ANLOAD INPUT FILE USER'S GUIDE**

## ANLOAD INPUT FILE

ANLOAD INPUT FILE can be created either manually or using RULE module ?EXDR/ANLDIN in LDEXPT. The input file will be named INFILE. The variables and format of the input file are listed below.

Card #1, format(2I6)

MODEL, IOPMP

MODEL

- =1 Gaussian Method
- =2 DPD Method
- =3 Monte Carlo Method

IOPMP

- =0 Single point calculation, no time step
- <>0 Time dependent evaluation

Card #2.1, format(2I6), required if MODEL=2

NBIN, NEND

NBIN : Number of bins

NEND : Number of intervals in each bin for the combined distribution

Card #2.2, format(I6), required if MODEL=3

NMC

NMC : Number of Sampling Points

Card #3, format(3E12.5, 6X, I6, E12.5)

TFIRST, TLAST, DELTSS, DELTTS, NPRT, MPRT

TFIRST: Starting time, the first time step to be evaluated at the time (TFIRST+DELT)

TLAST : time for the last time step, i.e. end time

DELTSS: delta time, i.e. time step size, for steady state load calculation used only with the duty-cycle-data option

For non-duty-cycle steady state option, the loads are evaluated at the mid-point and end-point of the steady state mission interval

DELTTS: delta time for transient state load calculation

NPRT : Number of time steps between printing

= 0 print only the output means and sigma's  
no saving of output to DPD.OUT (LU24)

= 1 print and save output means and sigma's  
print all nodal distribution functions every time step

= n print and save output means and sigma's every time step, print and save all nodal distribution functions every n time steps

MPRT : Interval of number of intermediate calculations for printing, e.g. MPRT = 20 means that printing of intermediate results is done for every 20 intermediate calculations

Card #4, format(I6,A20)

IZERO, NPWR

IZERO = 0

NPWR : power profile name

Card #5, format(I6,2E12.5)

IPWR, PWR0, PWRATE

IPWR : POWER options

= 0 Constant power, POWER=PWR0

= 1 Constant ramp rate,  
POWER=PWR0+PWRATE\*(TIME-TIME0)

= 2 POWER input from PFPWR profile

= 3 (Time & Power) points selected to be evaluated

= 4 Manual POWER profile input

PWR0 : power constant term

PWRATE: power ramp rate

Card #6.1, format(I6), required if (IPWR.GE.2)

NPRPWR

NPRPWR : number of pairs for the power duty-cycle-data  
profile or for the selected points (IPWR=3)

Card #6.2-6.n, format(6E12.5), required if (IPWR.GE.2)

PFPWR(I,J), J=1,2; I=1,NPRPWR

PFPWR(I,1) : time for the ith data point in the profile

PFPWR(I,2) : power level of the ith data point

Card #7, format(I6)

NLOAD

NLOAD : Number of independent loads  
maximum of 15 is allowed

Card #8.1, format(I6,A20,A4), repeat cards #8 as a set  
(i.e.#8.1-#8.n) NLOAD times required  
if (NLOAD <> 0)

IDPID(I), NAME(I), LOADNS(I)

IDPID(I) : the ith independent load ID number, see  
documentation on that or run LDEXPT to find out  
what they are

NAME(I) : the ith independent load name

LOADNS(I): the ith independent load stationarity

=1 non-stationary

duty-cycle-data input profile

=0 stationary, constant mean and variance

Card #8.2, format(6E12.5), required if (NLOAD <> 0)

CINOM(I,J), J=1,4

CINOM(I,J): the nominal engine coefficient set

Card #8.3, format(I6,3E12.5), required if (NLOAD <> 0)  
IGO(I),P1(I),P2(I),P3(I)

IGO(I) : pdf type  
= 0 constant  
= 1 uniform  
= 2 normal  
= 3 lognormal  
= 4 Rayleigh  
= 5 extreme value of type I  
P1(I) : mean  
P2(I) : standard deviation  
P3(I) : not used

Card #8.4, format(I6), required if (LOADNS(I) = 1)  
NPAIR

NPAIR : Number of the duty cycle profile data point

Card #8.5, format(6E12.5), required if (LOADNS(I) = 1)  
PFILD(K,J,I), J=1,3; K=1,NPAIR

PFILD(K,1,I) : the kth data point for time axis  
PFILD(K,2,I) : the kth data point for the Ith independent load  
PFILD(K,3,I) : the kth point for the standard deviation of the Ith independent load

Card #9, format(I6)  
NGF

NGF : Number of Component Local Variables (or loads)  
= 0 if there is no such variable

Card #10.1, format(2I6,A20), required if (NGF <> 0 )  
repeat card set #10 NGF times

LGF(IGF),LGFLAG(IGF),NAMEGF(IGF)  
LGF(IGF) : The IGF-th component local load ID  
LGFLAG(IGF): Not used  
NAMEGF(IGF): The IGF-th component local load name

Card #10.2, format(2I6,2E12.5), required if (NGF <> 0)  
IGOGFL(IGF),GFLNOM(IGF),GFLCOV(IGF),IGF=1,NGF

IGOGFL(IGF): the distribution type  
GFLNOM(IGF): the nominal value  
GFLCOV(IGF): the coefficient of variation

Card #11, format(I6)  
NRARE

NRARE : Number of rare events  
This option is not yet implemented  
Set NRARE = 0

Card #12.1, format(E12.5,A), required if NRARE <> 0  
repeat set #12 NRARE times

IDPID(NLOAD+NGF+II), NAME(NLOAD+NGF+II)  
IDPID(.): Load ID for the rare event  
NAME(.) : Name for the rare event

Card #12.2, format(2I6,E12.5), required if NRARE <> 0

IRARE(II), MPTRN(II), FREQ(II)  
IRARE(II): Not used  
MPTRN(II): Not used  
FREQ(II) : Not used

Card #12.3, format(I6,3E12.5)

IGO(II), P1(II), P2(II), P3(II)  
IGO(II) : pdf type of the ith shock  
P1(II) : mean parameter for the ith shock  
P2(II) : variance parameter  
P3(II) : not used

Card #13, format(I6)

NRESP  
NRESP : Number of dependent loads (or response loads)

Card #14.1, format(I6,A20), required if NRESP <> 0  
repeat card set #14 NRESP times

ICOMB(I), NAME(IB+I), STATE(I)  
ICOMB(I) : the ith dependent load ID number, see  
documentation  
NAME(IB+I): name of the ith dependent load, IB=NLOAD+NRARE  
STATE(I) : it is the value of the dependent load for which  
a limit state probability should be calculated

Card #14.2, format(4E12.5), required if (NRESP <> 0)

ANOM(I,J), J=1,4  
ANOM(I,J): nominal value coefficient set

Card #14.3, format(4E12.5), required if (NRESP <> 0)

(CINF(K,I,J), J=1,4), K=1,NLOAD  
CINF(K,I,J): influence coefficient set of the Ith dependent  
load varied due to the Kth independent load

Card #14.4, format(I6)

IDEP(I)  
IDEP(I) : Number of independent loads whose effect on the  
ith dependent load are to be evaluated

Card #14.5, format(12I6)

ITEMP(J), J=1, IDEP(I)  
ITEMP(J) : the independent load number as assigned by the  
order it entered in NLOAD loop

Card #15, format(I6)

NOUT

NOUT : Number of component loads whose pdf's are to be generated

Card #16.1, format(I6), required if (NOUT <> 0) and repeat card sets #16, #17, #18, #19 and #20 NOUT times

ITBCOM(I)

ITBCOM(I): component options

- = 1 for HPFTP turbine
- = 2 for HPOTP turbine
- = 3 for LPFTP turbine
- = 4 for LPOTP turbine
- = 5 for HGM fuel center transfer tube
- = 6 for LOX post or LOX post region A
- = 7 for LOX post region B
- = 8 for LOX post region C
- = 9 for HPOTP oxidizer transfer duct
- =10 for HPOTP discharge duct
- =12 for MCC liner

Card #16.2, format(I6,A20,A4)

IBLOAD(I),NAME(IB+I),GRNBLC(I)

IBLOAD(I) : the ith component load ID number

NAME(IB+I): name of the ith component load

where IB=NLOAD+NRARE+NRESP

GRNBLC(I) : the group name of the component load scaling coefficient file

- = "TBNO" for Turbine blade cross section nodal scaling coefficient set
- = "SCLM" for Structural Component Load Module loads
- = "NULL" if not needed

Card #16.3, format(I6,3E12.5)

IGO(IB+I),P1(IB+I),P2(IB+I),P3(IB+I)

IGO(IB+I) : distribution type for ith component load

IB = NLOAD+NGF+NRARE+NRESP

P1(.) : mean

P2(.) : standard deviation

P3(.) : not used

Card #17.1, format(I6,E12.5) required if GRNBLC(I)='TBNO'  
NXS,CFMNP

NXS : Number of nodes for the turbine blade (T/B)  
cross-section distributed loads  
CFMNP : Scaling coefficient for the T/B mean pressure term

Card #17.2-#17.n, format(6E12.5) required if GRNBLC(I)='TBNO'  
CFDSP(K),K=1,NXS

CFDSP(K) : coefficient of the torque scaling term for the  
K-th node of the X-section load

Card #18, format(2I6,E12.5) not required if GRNBLC(I)='SCLM'  
or 'TBNO'

ID1(I),ID2(I),C1(I)

ID1(I) : first dependent load ID for the ith component  
load, used for turbine blade pressure loads only  
for thermal load, set it equals to zero

ID2(I) : second dependent load ID, same usage as above

C1(I) : scaling coefficient for the ith component load

Card #19, format(I6) required if (GRNBLC(I).EQ.'NULL')  
ISD(I)

ISD(I) : =1 scaling depends on a single dependent load  
=2 scaling depends on two dependent loads  
>=999 used for thermal load scaling model  
=999 Default thermal load influence model  
=1000 Thermal mean value scaling model  
=1001 Thermal load object function model

Card #19.1, format(I6), required if (ISD(I).EQ.999) and  
(GRNBLC(I) = 'NULL')

NBD(I)

NBD(I) : number of boundary loads for the ith component  
load  
used for thermal load only

Card #19.2, format(I6,A20), required if (ISD(I).EQ.999) and  
(GRNBLC(I) = 'NULL')

IDBDL(I,IBD),NAMEBD(I,IBD) for IBD = 1,NBD(I)

IDBDL(I,IBD) : the IBD-th boundary load ID for the I-th  
component load

NAMEBD(I,IBD) : the corresponding IBD-th boundary load name

Card #19.3, format(6E12.5), required if (ISD(I).EQ.999) and  
(GRNBLC(I) = 'NULL')

IDBDL(I,IBD),BDLNOM(I,IBD) for IBD=1,NBD(I)

IDBDL(I,IBD) : the IBD-th boundary load ID  
for the I-th component load

BDLNOM(I,IBD) : the IBD-th boundary load nominal value

Card #19.4, format(I6), required if (ISD(I).GE.999) and  
(GRNBLC(I) = 'NULL')

NBDDL(I,IBD)

NBDDL(I,IBD) : number of dependent loads required in the  
IBD-th boundary load influence model

Card #19.5, format(2I6,2E12.5), required if NBDDL(I,IBD) <> 0

LCBDDL(I,IBD,IBDDL),MPBDDL(I,IBD,IBDDL),CINFBD(I,IBD,IBDDL)

for IBDDL=1,NBDDL(I,IBD)

LCBDDL(I,IBD,IBDDL) : load type of IBDDL-th dependent load  
for the IBD-th boundary load  
= 0 system dependent load  
= 1 component local load

MPBDDL(I,IBD,IBDDL) : dependency map of the IBD-th boundary  
load to the dependent loads

CINFBD(I,IBD,IBDDL) : influence gain of the IBD-th boundary  
load due to the corresponding  
dependent load

Repeat card #19.5 input NBDDL(I,IBD) times

Repeat card set #19 NBD(I) times

Card #20, format(I6), required if (ISD(I).GE.999) and

(GRNBLC(I)='NULL' or GRNBLC(I)='TBPR')

NODETM(I),NODEST(I),NODEBG(I)

NODETM(I) : number of nodes for evaluation for the ith  
component load

NODEST(I) : do the component load calculation every other  
NODEST(I) nodes

NODEBG(I) : do the calculation starting from the NODEBG(I)  
node

Card #21, format(A) required if (NMP(IR) <> 0)

TITLE

TITLE : mission phase title

Card #22, format(I6), repeat card set {#21,#22} NRESP times

NMP(IR) for IR = 1 to NRESP

NMP(IR) : number of mission history phase for ir-th  
dependent load

Card #23.1, format(I6,2E12.5), required if (NMP(IR) <> 0) and  
repeat card set #23 NMP(IR) times  
MP(IR,IMP),STIME(IR,IMP),ETIME(IR,IMP), for IMP = 1 to NMP(IR)  
MP(IR,IMP) : Mission phase type for the IR-th dependent  
load & the IMP-th mission phase  
= 1 simple transient spike model  
= 2 quasi-steady state using generic  
transient influence model  
= 3 steady state  
= 4 transient arrival model  
= 5 transient arrival model with uniform  
distribution for the number of random  
spikes  
= 6 SSME default start transient  
= 7 SSME default shutdown transient  
STIME(IR,IMP) : start time of the IMP-th mission phase  
ETIME(IR,IMP) : end time of the IMP-th mission phase

Card #23.2, format(I6) required if (MP(IR,IMP) = 1)  
NS(IR,IMP)  
NS(IR,IMP) : number of simulation for the transient spike

Card #23.3, format(I6,2E12.5) required if (MP(IR,IMP) = 1)  
IDA(IR,IMP),AMP(IR,IMP),SDAMP(IR,IMP)  
IDA(IR,IMP) : spike amplitude distribution type  
AMP(IR,IMP) : mean spike amplitude  
SDAMP(IR,IMP) : standard deviation of the spike

Card #23.4, format(I6,2E12.5) required if (MP(IR,IMP) = 1)  
IDT(IR,IMP),TIMEJ(IR,IMP),SDTJ(IR,IMP)  
IDT(IR,IMP) : spike occurrence time distribution type  
TIMEJ(IR,IMP) : mean time of arrival  
SDTJ(IR,IMP) : standard deviation of mean arrival time

Card #24.1, format(2I6), required if (MP(IR,IMP) >= 4)  
NS(IR,IMP),IDLAY(IR,IMP)  
NS(IR,IMP) : number of simulation for transient spike  
arrival  
IDLAY(IR,IMP) : fix delay time of the secondary spikes

Card #24.2, format(I6,2E12.5) required if (MP(IR,IMP) >= 4)  
NFIK(IR,IMP),RAMDA(IR,IMP),WIDTH(IR,IMP)  
NFIK(IR,IMP) : transient spike arrival type  
< 0 for subsequent spikes to arrive at an  
IDLAY WIDTH later  
= 0 for spikes to arrive at a mean time  
TIMEJ(IR<IMP) input next  
> 0  
RAMDA(IR,IMP) : transient spike mean arrival rate  
WIDTH(IR,IMP) : transient spike width parameter

Card #24.3, format(I6,2E12.5), required if (MP(IR,IMP) >= 4)  
IDA(IR,IMP), AMP(IR,IMP), SDAMP(IR,IMP)  
    IDA(IR,IMP) : distribution type for the spike amplitude  
    AMP(IR,IMP) : spike amplitude mean value  
    SDAMP(IR,IMP) : spike amplitude standard deviation

Card #24.4, format(I6,2E12.5), required if (MP(IR,IMP) >= 4)  
IDT(IR,IMP), TIMEJ(IR,IMP), SDTJ(IR,IMP)  
    IDT(IR,IMP) : spike occurrence time distribution type  
    TIMEJ(IR,IMP) : mean occurrence time  
    SDTJ(IR,IMP) : standard deviation of the occurrence time

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13. ABSTRACT (Maximum 200 words)  Generic load models are described with multiple levels of progressive sophistication to simulate the composite (combined) load spectra (CLS) that are induced in space propulsion system components, representative of Space Shuttle Main Engines (SSME), such as transfer ducts, turbine blades and liquid oxygen (LOX) posts. These generic (coupled) models combine the (deterministic) models for composite load dynamic, acoustic, high-pressure and high rotational speed, etc., load simulation using statistically varying coefficients. These coefficients are then determined using advanced probabilistic simulation methods with and without strategically selected experimental data. The entire simulation process is included in a CLS computer code. Applications of the computer code to various components in conjunction with the PSAM (Probabilistic Structural Analysis Method) to perform probabilistic load evaluation and life prediction evaluations are also described to illustrate the effectiveness of the coupled model approach.				
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